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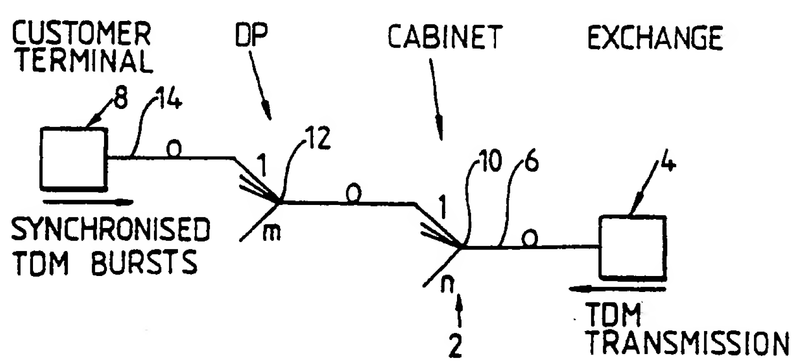

(57) Abstract

A passive, all optical communications network in which a single optical source in a central station serves many outstations (e.g. telephones in customer's premises). Time division multiplexed optical signals from a laser source are transmitted along a single optical fibre (6) from a central station (4). The signal is split between several secondary fibres at a first splitter (10) (e.g. array of passive couplers) and between further sets of fibres at a second set of splitters (12). At this stage there are 120 individual fibres to customer's premises (8). Digital speech or data is sent back to the central station by a laser in the customer's premises operating in a low duty-cycle mode. The 120 data streams are interleaved at the branching points.

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OPTICAL COMMUNICATIONS NETWORK

This invention relates to optical fibre communications networks and in particular, but not exclusively, for the provision of networks serving single line telephony out stations.

One approach to the deployment of an optical fibre communications network is the so called FAS network as described in the paper entitled "Future evolution of British Telecoms private circuit and circuit switched services" by Dr. S O'Hara, IEE Colloquium February 1986 which is aimed at the telephony and data needs of large business customers with ten or more lines. A principal drawback of the FAS type architecture is that it relies on direct, dedicated point-to-point optical links from each customer to the local exchange. This means that small to medium business customers with typically only two to five lines cannot be economically connected to a FAS type network. For residential customers with a requirement for single line telephony the cost requirements are still more severe and it appears from present estimates that it is unlikely that a direct optical connection per customer from the exchange will ever be a commercial possibility.

One proposal for extending the use of optics beyond large business customers, is to provide new broadband services in addition to the telephony service, such as cable television for example, as described in "The British Telecom switched star network for CATV" by W.K. Ritchie, BT Technology Journal, Sept. 1984.

In such an approach the strategic aim is to seek to move towards an integrated multiservice network, conveying

both narrowband services (telephony+data) as well as broadband (entertainment TV, video library service etc) so that the relatively high cost of extending an optical connection to the residential customer can be justified by the combined revenue of both types of service. The major difficulty with this approach, however is that there is not yet an adequate customer demand for such services to justify the very substantial investment that would be required. The view is nevertheless widely held both in the UK and abroad that the eventual development of integrated multiservice networks is inevitable and will most likely occur at some stage during the 1990's while such circumstances continue to prevail, any further extension of optical technology into the Local Loop must be largely justified on the basis of providing cost effective solutions for the provision of the basic telephony/data services.

One possible approach is a partial optical solution in which the optical network extends only as far as the street distribution point (DP) (that is the point from which individual customer links are distributed), with the known copper wire link being used for the final feed to the telephony/data customers.

There are several disadvantages with this approach. It requires the use of remotely stationed electronics in the field in concentrating traffic economically onto highly multiplexed feeders back to the exchange. Active electronics is in general required both at the street Cabinet level and the DP. The latter is also street located except for business customers large enough to justify their own DP. For such a system there are potential problems related to the maintenance, reliability, power feeding and power consumption of the remote electronic nodes.

It is an object of the present invention to provide an optical fibre communications network which has the potential to provide economic telephony links to smaller line users whilst reducing the need for outstationed electronics. Accordingly there is provided an optical communications network comprising a central station, a plurality of outstations, and a branch network of waveguides comprising a single waveguide from said central station which carries, in use, time or frequency division multiplexed optical signals for said outstations, and one or more passive splitters to distribute optical power from said waveguide to two or more secondary waveguides for onward transmission to said outstations, said network being adapted for return signals from said outstations to be passively multiplexed onto said single waveguide, or a similar single waveguide.

A passive optical fibre communications network according to the present invention provides low fibre count cable requirements, sharing of exchange opto-electronic devices and reduced amounts of installed fibre. It also provides low maintenance costs due to the reduction of electronic components in the customer terminals that are in need of maintenance thereby achieving to a large degree a minimum cost, 'fit and forget' network.

A further advantage of a network according to the present invention is that it is expected to allow a full-fibre network to all classes of customers at a cost which can be reasonably charged for a telephony only service which can be progressively enhanced by wavelength division multiplexing techniques to provide an all-optical multiservice broadband network as demand dictates.

One of the principal features of the present invention which distinguishes it from hitherto known telephony

networks is the adoption of multiple customer shared access back to the exchange.

Preferably the central station has a ranging means for detecting the temporal position of the signals from the outstations within a predetermined multiplex frame period which is responsive to any deviation of the positions from desired positions to send correction signals to the outstations, the outstations including a variable delay means and being responsive to the correction signals addressed to it by the central station to vary the variable delay whereby the return signals are passively multiplexed at the correct frame positions.

The use of ranging to control the time domain passive multiplexing permits very high bandwith efficiency by allowing bit interleaving of the multiple customer signals with little or no inter-bit gap in the multiplex back to the central station. It is expected that time efficiencies of 95% are possible.

Preferably the network provides a 128 optical split for each exchange line with a 20 Mbit/s bitrate of operation. This bitrate/split combination allows an attractive set of options for both business and residential customers. Thus at a chosen maximum split of 128 (120 customers plus 8 test ports), capacity would be available to feed each customer, if desired, with an ISDN 144kbit/s channel or equivalent capacity. For business districts, where multiple line customers are in the majority, a lower optical split would be employed, allowing higher capacities to be delivered per customer. In the first instance networks may be planned to deliver capacities well within the 20Mbit/s feeder capability, leaving substantial margin for uprating both in terms of providing additional numbers of 64kbit/s lines or introducing, say, ISDN service.

In such a network it is preferable that all systems be designed to a fixed optical loss criterion appropriate to the full 128 way split, regardless of the actual degree of split initially required by the first customer set. This would give great planning flexibility, allowing additional customers to be connected to the network as demand arises. Thus all stages of the 128 way matrix would be implemented at the outset, giving the full loss specification, but with only the minimum number of couplers being installed to provide connections to the initial customers.

Although a network may be provided which is a fully passive optical network with a direct fibre feed into various the business or residential customers, it can be linked to some electrical links to provide a hybrid variant in which there is an active electronic node at the DP and copper connection to the subscriber but which is compatible with, and fully uprateable to, the optical network according to the present invention. Such a system may prove most economic for the early penetration of the residential market where cost targets for telephony service alone are at their most severe.

Another important advantage of the present invention is network evolution. This architecture offers considerable opportunity for evolution towards the broadband multiservice network of the future via the addition of separate optical wavelengths carrying the new broadband services on the same passive optical network. This should be possible without disrupting, or loading the costs, of the original service provided adequate planning and provision is made at the time of the initial installation.

The component parts of the applicant's optical network can be conveniently classed under the major subject areas of 1) Optical Technology and Optical System Design, 2) Optical External Plant, 3) Bit Transport System Design and 4) Network Interface and Overall System Design, which will now be discussed in turn.

I Optical Technology and Optical System Design

a) Network Topology

Choice of topology is an important consideration in minimising the overall cost of the network. There are several topologies that could be implemented to provide a passive optical network according to the present invention. Key issues in the final choice will be: provisioning and maintenance costs, services provided, growth strategy and potential for evolution to broadband services. For each option that may be considered the initial network cost arguments also need to be carefully weighed against the potential for future evolution. Choices include full bidirectional working, partial bidirectional working separate upstream and downstream links between the exchange and a customer, and the use of copper wire in the link between the DP and some customers in an otherwise all optical fibre network. These will be considered in detail below.

b) Optical Splitter Technology

The optical power splitters are conveniently fused fibre couplers. However, longer term options such as holographic devices when fully developed may provide the means for achieving potentially lower costs.

c) Customer's Laser Transmitter Module

The customer's laser is one of the most critical components affecting the customer costs. The detailed operational requirements for any device required to be low cost specifically determine the choices in package design,

drive and protection electronics and laser reliability (coupled with environmental performance). For example an uncooled package is likely to be desirable for a low cost transmitter module in order to reduce power consumption, simplify the package design and assembly and reduce overall transmitter costs. The removal of the cooler, however, results in the temperature of the laser being uncontrolled with a consequent increase in the laser degradation rate at the upper end of the ambient temperature range. In addition the temperature dependence of laser/fibre coupling will become more critical. In the system high pulse powers are required to overcome the splitting losses of the network. If excessive peak optical powers are to be avoided (leading to high current densities and lower reliability) then low cost packages with good coupling efficiency will be desirable. Although the bitrate of 20Mbit/s presently envisaged permits the use of low cost CMOS VLSI, transmitters/receivers operating at 45-50Mbit/s could alternatively be provided. Such devices, although using costlier electronics, may in fact be cheaper overall bearing in mind that packaging costs are likely to be dominant. The latter will be influenced chiefly by the degree of factory investment/automation committed which will in turn be determined by anticipated production volume.

It will be appreciated that the foregoing relates to the costs of implementing a network according to the present invention and that more expensive laser devices could be employed although this would be likely to result in increased costs.

The customer transmitter is preferably operated on a low duty cycle in as described in the applicants co-pending UK patent application UK 8700069 filed 5th January 1987. Further, it is preferable that the laser

output level is controlled by remote monitoring by the exchange as described in the applicant's co-pending UK patent application 8710736 filed 6th May 1987 which allows elimination of the monitoring photo-diode from the customers transmitter or frees it to be used as a detector.

d) Optical Blocking Filter

An optical blocking filter is a preferred component, as it ensures that future upgrading of the network is possible without distrubing existing telephony customers. For some network topology options (e.g. full duplex) it may assist in coping with the problems of crosstalk arising from reflections. Thus, if different wavelengths are used in the upstream and downstream directions, narrow band filters can be used to discriminate against reflected light before it reaches the optical receivers.

Various technologies are or will be available with grating, interference and holographic devices offering potential for achieving low cost devices.

e) Exchange Optical Equipment

The exchange optical equipment although not so cost sensitive as the customer equipment devices has a more demanding performance specification. The laser transmitter needs to have a high mean output power and a well controlled and tightly specified centre wavelength. Preferably, single longitudinal mode source (eg. DFB or DBR lasers) are used to ensure that only a minimum width of optical spectrum needs to be allocated to the initial telephony service, thus conserving valuable spectrum as much as possible for future service growth. The receiver is required to be sensitive and yet cope with timing jitter, due to imperfect ranging delay compensation, and unequal optical power in adjacent bits, due to unequal path attenuations and customer laser output power tolerances. Thus it is preferable that the receiver is a

DC coupled design or at least has the threshold level in the decision circuitry DC coupled relative to the zero level of the optical bit stream.

II Optical External Plant

a) Passive Network Design

Ideally the network is designed to be able to grow and change, both in terms of telephony customers being added and in terms of new services (wavelengths). In its most preferred form, a fully duplexed, branched network, the wavelength range of the plant and sensitivity of the network to reflections are critical aspects which have significant effects on the sizing of the network and the specifications put on each component. Studies by the applicant have shown that the effect of reflections is significant and their effects need to be taken into consideration unless a fully duplicated fibre network is to be used for upstream and down. Wavelength range of plant is important to the addition of new service wavelengths. The wavelength flatness of each component, and an overall matching of components to optimise power budget need to be considered in the design of a network according to the present invention.

b) Components

Critical elements here are wavelength flattened coupler arrays, optical blocking filters, connectors for use in customers equipment and splicing techniques suitable for use on a wide scale in all environments. The first two items on this list have already been discussed in section 1 above. An interference (or other) optical filter may alternatively be incorporated within the connector at the customer's premises. The alternative strategy of eliminating the customer's connector and relying on a 'hard wired' approach is another possibility. Other methods of incorporating the optical filter in the

system can be considered including, for example, fibre based devices which would need to be spliced, either in the customer equipment or the lead-in optical cabling.

III Bit Transport System Design

The Bit Transport System (BTS) for the network is required to carry the services between the exchange service access unit and the customer equipment service access unit. The service access unit at the exchange end will take a network service eg. analogue telephony, primary rate ISDN (2Mbit/s), 64 kbit/s data circuit etc. and convert it to a standard interface for the bit transport system. The BTS will then transport this service to a further standard interface in the customer equipment. At this point a customer based service access unit will convert the interface into the required format for the customer equipment eg. analogue telephony etc.

Besides the services and any associated signalling etc. the BTS must also carry the system house keeping messages. These house keeping messages are for the smooth operation of the system, not the services being carried, and will include the following system functions:

(i) A ranging protocol to keep each channel correctly timed at the exchange end of the system.

(ii) The ability to remotely turn off customer equipment lasers for fault diagnoistic purposes.

(iii) To enable remote setting of the drive current to the customer lasers to control the optical output power.

(iv) To provide terminal/customer identification, validation and channel assignment.

(v) To provide fault diagnostic data and system interrogation messages.

The bit transport system of the network may eventually

need to carry and interface to many disparate services, for example

- Analogue Telephony - out of channel signalling (64 + 8 kbits/s)
- Analogue Telephony - in channel signalling (64 kbits/s)
- Basic Rate ISDN (2 x 64 + 16 kbits/s)
- Primary Rate ISDN (2048 kbits/s)

Although the main initial requirement is expected to be the carrying analogue telephony with out-of-channel signalling (64 + 8 kbits/s) it is highly desirable to design a BTS with a framing and channel assignment structure that can carry all the services mentioned above by changing the service access units only. This is important for example for the future compatibility with new services.

The highest common factor bit rate for the above example services is 8 kbits/s. Because this rate is also the sampling rate for speech services, corresponding to a 125us basic frame period, each bit within the 125us frame corresponds to an 8 kbits/s basic channel. A customer service is then provided by assigning an integer number of these 8 kbits/s channels for example, analogue speech with out-of-channel signalling would be assigned 9 channels each of 8kbits/s, arranged to preserve speech integrity, corresponding to 9 bits within the 125us basic frame, a basic rate ISDN service would be assigned 18 such 8 kbits/s channels ie. 18 bits within the basic 125us frame.

In addition to the information channels within the basic frame there is also the one 8 kbits/s housekeeping channel for each customer optical termination. This carries house keeping messages. This means that a customer requiring 1 analogue telephony channel with out-of-channel signalling has a total of 10 basic 8

kbits/s channels assigned to him and correspondingly a basic rate ISDN customer has assigned a total of 19 basic 8 kbits/s channels.

Another possibility for the basic frame structure is to use a bit interleaved protocol in order to maximise any advantage to be gained by operating the customer laser in a low duty cycle mode, while retaining the same frame structure for both directions of transmission. This means that rather than transmitting the bits (8 kbits/s channels) assigned to a particular customer sequentiality, they would be spread out fairly uniformly throughout the 125us basic frame period.

b) Auto Ranging System

Periodically within the total structure, spare time (when service data is not being transmitted) must be reserved for the ranging process as noted above. The amount of time reserved for ranging determines the geographical distance over which ranging can be carried out. The frequency at which ranging occurs determines the bit rate overhead that will be incurred. To simplify timing and synchronisation issues the ranging period should be integer multiples of the basic frame period (125us). A 125us frame period allows adequate time to range over a geographical distance of 10km while 250us will allow ranging over 20km. In order to reduce the bit rate overhead to approximately 1 °/o a 10ms periodicity for ranging is possible (this corresponds to 80 basic data frames followed by one ranging frame, a bit rate increase of 81/80).

Preferably there are 3 levels or phases of ranging:

Phase 1 ranging occurs for Optical Terminations (OT) when they are first connected to the system. In this case the exchange end has no information regarding the path delay to and from the OT. The exchange end will therefore

use the ranging period to measure this path delay and then subsequently inform the newly fitted OT what local delay to set up for correct timing.

Phase 2 ranging occurs for terminals already connected to the network when a new call is initiated or when the optical terminal is turned on after disconnection from the local power supply. In this case the ranging protocol will be checking the delay period previously assigned to an OT and if necessary making small corrections. In order to maximise laser life times, it is envisaged that the OTs will not be transmitting unless they are carrying traffic, therefore ranging will not be occurring for idle terminals.

Phase 3 ranging is carried out periodically while an OT is carrying traffic. The exchange end will be monitoring the timing from each active terminal and instructing these terminals (using the house keeping channels) to make minor corrections to the local delays if any of the timings start to drift.

IV Network Interface and Overall System Design

The BTS discussed in the previous section provides a means of transporting bits across the passive optical network. Appropriate interfaces are needed between the BTS and digital exchange, and between the BTS and customers apparatus to enable services to be carried which meet the overall requirements of the communications network. The overall system encompasses, testing, network interfacing, reliability, network management, powering and so on.

a) Service

The primary service requirement of the network according to the invention is, at present, analogue telephony. Such a service has to be carried cost effectively between an analogue direct exchange line

interface at the customer's premises and a DASS2 2.048Mbits/s interface to be 64kbit/s switched network. Besides analogue telephony there are also a wide variety of other services which are presently supported in an analogue manner over the copper pair local network. The BTS frame structure and protocols should be flexible enough to transport basic rate ISDN or CATV signalling. It is an important principle that the addition of future new services is not prejudiced by a restrictive 'telephony-only' design. However, the provision of a minimum cost network may conflict with this objective and a fine balance may need to be struck. The methods that can be used to provide additional service include increased use of TDM by increasing the bit-rate and extending the frame structure, the introduction of WDM, and the provision of additional fibres. These methods are described below.

b) <u>Network and Customer Interfaces</u>

A primary requirement for the UK network will be to interface the network to the 64kbit/s switched network over 2.048Mbit/s DASS2 connections with statistically multiplexed signalling in time slot 16 but the present invention is not restricted in its application to this particular requirement.

A range of customer units is envisaged to cater for the multiple line business user through to the single line residential user. Modularity of the basic elements will be fundamental to any customer unit design to allow for operational flexibility.

c) <u>Powering</u>

The network termination at the customer's premises relies on AC mains power provided by the customer. This is a departure from the current practice on the copper

pair network of power feeding from the local exchange.

Specific embodiments of the present invention will now be described, by way of example, and by reference to the accompanying drawings in which -

Figure 1 is a schematic diagram of an optical fibre communication network according to the present invention;

Figure 2 is a schematic diagram of the network of Figure 1 arranged for full bidirectional operation;

Figure 3 is a schematic diagram of a network arranged for partial bidirectional operation;

Figure 4 is a schematic diagram of a network having separate downstream and upstream optical paths between a customer and an exchange;

Figure 5 is a schematic diagram of a network according to the present invention to which there are customer terminals connected to a DP by copper pairs;

Figure 6 is a schematic diagram of a fused optical coupler array for use with the networks of Figures 1 to 6;

Figure 7 is a schematic block diagram of a bit transport system for use with the networks of Figures 1 to 5;

Figure 8 is a schematic block diagram of a secure transmission module which may be used in customer terminals of the networks of Figures 1 to 5;

Figure 9 is a schematic diagram of a multiplex system usable with a network according to the present invention;

Figure 10 is a schematic diagram of an experimental arrangement simulating a full installed network;

Figure 11 is a table showing the possible enhancements of a basic telephony network according to the present invention and the associated technology enhancements

expected to be required to provide the enhancements; and

Figures 12 to 14 show three stages in a possible evolution of a network according to the present invention initially carrying a telephony service only to an extended multiservice network.

Figure 15 to 19 show the Frame Structure of the bit transport system shown in Figure 7;

Figure 20 - 22 show the Head End of the Bit Transport system of Figure 7;

Figure 23 - 25 show the Customer End of the Bit Transport System of Figure 7:

Referring to Figure 1 there is shown the basic concept of a network according to the present invention. An optical fibre communications network 2 is shown in which a central station (exchange) 4 is linked via a single mode optical fibre 6 to 120 customers 8, of which only one is shown for clarity. A two level optical split is employed at cabinet and DP level by means of wavelength flattened optical couplers 10 and 12 respectively. The fibre length between exchange and cabinet is 1.6km and between cabinet and individual customers via the DP is in the order of about 500m.

Each customer 8 receives a fibre 14 from a DP and, via this, a TDM signal broadcast from the exchange 4. The customer's equipment accesses the particular time slots of the TDM intended for that destination plus any associated signalling channels. Further interface circuitry (not shown) provides the detailed services required by the customer, eg analogue telephony or ISDN services. Customers transmit digital speech or data back to the exchange using OTDMA in a low duty-cycle mode with the converging traffic streams passively interleaving at the DP and cabinet branching points. Correct timing is

achieved by synchronising the customers' equipment to an exchange clock and using a ranging protocol to set a digital delay line in the customers' equipment to access vacant time slots at the exchange receiver.

Two additional amplitude thresholds are provided at the exchange receiver which allow monitoring and control of the received amplitude. Each customer's time slot is sampled sequentially and his transmitter power is adjusted via a downstream telemetry path so that the received signal falls between the two thresholds. One of the advantages of this approach is that it is not necessary to provide a monitor photodiode at each remote transmitter.

The cost of the customer's transmitter may be further reduced because it operates in a low-duty cycle mode. By operating in this mode there is no need for temperature control of the source. The duty cycle depends upon how many time slots are being accessed and for a single line customer they may be as low as 1:128 for an 128 way split to customers.

Provisional system design views favour an optical split of up to 128 ways and a transmission rate of 20Mbit/s. This allows an attractive set of service options for both business and residential customers. Sufficient capacity is available to feed up to 120 customers (allowing 8 spare test ports) with a 144kbit/s ISDN connection. Business customers requiring larger capacities would access multiple time slots as required up to the maximum capacity of the system.

Since downstream traffic is broadcast, the system design requires measures to ensure communications security. Casual access to time slots can be prevented by appropriate design of the customer's terminal 8 for example by the use of blocking filters. Time slots are accessed according to the setting of the digital delay

line in the customers' equipment. This function is remotely controlled by the exchange 4.

Referring now to Figure 2 the optical network 2 of Figure 1 is arranged for fully bidirectional operation. Problems with reflections and the duplex coupler losses are reduced by operating the network with different upstream and downstream wavelengths. Thus with the downstream (from the exchange 4) traffic carried at 1550nm and the upstream at 1330nm, the couplers 16 at each end of the system can be designed to have much lower insertion loss. Additionally the use of blocking optical filters 18 at the customer terminal receivers (to reject the reflected light) eases crosstalk problems considerably, although of course at the expense of providing the filter function.

The fully bidirectional network has the advantage of minimising the amount of fibre installed but suffers more severely from potential crosstalk problems than the other networks, hence the use of separate upstream and downstream wavelengths and the use of filters 18. The network uses a minimum of 2N couplers (where N-number of customers), 2 couplers per customer. The crosstalk arises from light reflected back from any unterminated fibre end within the network (when ends are prepared to splice-in new customers for example). An additional drawback of this full duplex topology is that the splitters required at each end of the system give rise to an increase of around 6-7dB in optical path loss over other topologies.

An alternative network is shown in Figure 3 in which the couplers 16 of Figure 2 are incorporated into the cabinet and DP splitters, the latter for customer 8 being designated as splitter 20. This uses a minimum of 2N-1 couplers, one less than the full duplex network but requires more fibre. It also has an additional 3-3.5dB

optical power budget available that could be used to increase the optical split size (and hence reduce the amount of fibre per customer) or relax system engineering margins. Again further discrimination from reflections can be obtained by employing different upstream and downstream wavelengths and optical filtering.

Referring now to Figure 4 an optical fibre communications network has physically separate upstream and downstream optical paths 2 and 2' with respective equivalent components of Figure 2 marked with the same numbers and the same numbers primed, respectively.

The network shown in Figure 4 has physically separate upstream and downstream optical paths and therefore reflection problems are completely avoided. It uses 2N-2 couplers, two less than the number required for the full duplex system but uses twice as much fibre. However the amount of fibre per customer is small in these shared access networks so that the fibre cost over head is not critical to the economic viability of the system. In addition an extra 6-7dB of power budget is available which could in principle be used to quadruple the split size and potentially further reduce the amount of fibre per customer. Because the upstream and downstream paths are physically separate there is no advantage in using different wavelengths for the two directions of transmission.

It is expected that the full duplex shown in Figure 2 should prove to be the most cost effective approach. However some consideration should be given to network of Figure 4 where it is possible that the practical engineering advantages associated with the more relaxed optical power budget and lack of reflection problems may outweigh the extra fibre cost involved.

The network of Figure 5 illustrates an option based on the network of Figure 2 for early penetration to the residential telephony market. It includes an active electronic distribution point at the DP that would exploit the existing copper drop wire 24 connected to an otherwise totally passive optical architecture. This topology could be useful in the short to medium term where full network according to the present invention is provided to a high street business community and whilst in order to reduce duct congestion by removing copper cables, residential customers on the same route are to be connected to the system. As the optical technology continues to reduce in cost the active DPs would be removed and the full network extended to the residential customers to pave the way for the penetration of new broadband services.

An example of a fused fibre coupler as used in the optical networks of Figures 1 to 5 is shown at Figure 6.

The fused fibre coupler splitter 30 is fabricated from a multi-stage array of 'elemental' 2X2 couplers 32. In order to preserve the potential of both optical windows in the fibre (1300nm and 1550nm), wavelength flattened devices are used.

The technique for fabrication of 2X2 elemental couplers is described in the applicant's co-pending UK patent application no. 8519183. Improvements in coupling ratio tolerances and flatter spectral characteristics in particular are desirable as these have a direct bearing on the optical power budget, optical split size and overall system economics. Initial results indicate coupling ratio variation of around 1dB across the complete optical window (1275nm - 1575nm), implying a need for careful choice of coupler parameters and system wavelengths if, for example, the 128-way split target mentioned above is to be realised economically.

The optimum size of the total split is affected by various factors and any convenient figure may be chosen. Factors affecting split size are: cost, optical power budget, system bit rate, service requirements, number of lines per customer etc. Based on a simple optical power budget model for the bidirectional network of Figure 2 and the assumption of a maximum system bit rate of around 20Mbit/s has suggested a binary split size of 128. This would correspond to 120 customers plus 8 test access points with the capacity available to feed 144bit/s ISDN (or bit rate equivalent) to each individual customer.

Referring now to Figure 7, there is shown a bit transport system (BTS) for use with the network according to the present invention. A service access unit 34 at the exchange 4 will take a network service, for example analogue telephony, primary rate ISDN (2 Mbit/s), 64 kbits data circuit and so on, and convert it to a standard interface for the bit transport system. The BTS will then transport this service to a further standard interface in the customer equipment 8. At this point a customer based service access unit 40 will convert the interface into the required format for the customer equipment eg analogue telephony etc.

Figures 15 to 19 show in more detail a BTS capable of carrying an ISDN service to 128 customers.

The basic frame (BF) (Figure 15) is shown to be made up of 2304 bits of data traffic and 128 single bit Housekeeping channels and 12 bits for fibre ID which in this example are not being used and so are spare.

Each of the 2304 bits of data traffic corresponds to an 8kbit/s basic channel from a 30 channel TDM highway. A Customer service is then provided by assigning an integer number of these 8kbit/s channels to each Customer. For a basic rate ISDN service each Customer is

assigned 18 such 8kbit/s channels ie 18 bits within the basic frame. Thus 2304 represents 128 ISDN service channels each of 18 bits.

The basic frame contains all the data from all these channels which occurs within one sampling period. A BF thus effectively contains 12 microseconds of data from the 2304 8kbit/s channels and the 128 housekeeping channels. The BF is identical for both Head End to Customer End (broadcast) and Customer End to Head End (return) transmissions.

Figure 16 shows a multiframe which is made up of 80 basic frames and a Sync frame which has a frame period equivalent to two BFs. The multiframe has a period of 10 ms and comprises 200408 bits. Transmission through the Bit Transport System therefore occurs at a rate of 20.0408 Mbit/s.

The broadcast SF (from the Head End) serves a different function to the return SF (from the Customer End).

Figure 17 shows the Sync Frame from the Head End in more detail. The last 140 bits of the Sync Frame from the Head End are essential to system operation as they are used to transfer the Main Frame Sync from the head end to the Customer end. In other words, the last 140 bits form a MF Sync pattern comprising for example 140 zero bits, which is identified by the Customer end thus enabling the Customer end to locate and receive the data intended for it from the Main Frame. The first 4748 bits ensure that broadcast and return framing structures have the same format. These 4748 bits may also be used for fibre identification purposes and general purpose broadcast system maintenance.

Figure 18 shows the Sync Frame from the Customer end. This SF is used primarily for ranging although it may also

be used to identify active Customer ends connected to the fibre at any point in the network. The return SF is divided into segments for phase 1 ranging and for phase 2 ranging.

Phase 1 ranging uses the first 4288 bits. This provides a little over 200 us of blank time in which one Customer End at a time may be ranged. To do this, a housekeeping controller at the Head End will instruct a newly installed Customer End to transmit a single pulse at the start of the phase 1 period. The Controller will then identify how many bits delay there is before this pulse arrives at the Head End. After several attempts it will have determined the correct bit delay factor and will instruct the Customer End to proceed to phase 2 ranging using this correction.

The 660 bits for phase ranging and fibre ID are shown in more detail in Figure 19.

Each of the 128 Customer Ends has its own 5 bit wide phase 2 ranging subslot within the last 640 bits of the SF. These are used by the Head End controller to adjust the transmit phase of the Customer End so that pulses arrive at the Head End aligned with the Head End Clock. This obviates the need for any clock recovery at the Head End. Additionally, the return path transmission can be a simple on/off pulsing of the Customer End transmitter, which reduces the life requirements of the Customer End laser. It also results in improved efficiency of use of the return path, as no clock recovery information need be transmitted.

Once the initial phase 2 ranging has been completed, the Customer End is instructed to go"on line". It will now activate its return path housekeeping channel and also its ID Sync pulse. All Customer Ends active in the network transmit this ID pulse at the same instant.

It provides a high power marker pulse for return path ID detection. An ID detector at the Head End monitors the transmission of this high power pulse, then monitors the subsequent 5 bit wide sub-slots to see if any transmission is present for example, if sub-slot 3 has a pulse in it, Customer End 3 is active in the fibre at this point. It is necessary to monitor the broadcast direction to find out which network this is.

The high power ID pulse in conjunction with sub-slots may also be used to detect whether a particular Head End is transmitting using an optical detector such as an optical coupling device as described in our copending patent application No 8706929 at any point in the network. Such a device may be used by clipping it onto a fibre whose outer coating has been removed. This is useful to engineers working in the field, who need to be sure that if they wish to cut a particular fibre, they correctly identify that fibre.

Referring again to figure 17 the 140 bits for MF Sync pattern may also be used to detect breaks in the fibre network. Using the principles of Optical Time Domain Reflectometry, it is known that a signal transmitted along a fibre will be reflected at a break. The amplitude and frequency of these reflections may be used to determine the location of any breaks in the fibre. Since the MF Sync pattern is transmitted at regular intervals, a receiver at the Head End may be tuned to recognise the pattern. The time between transmission of the pattern and reception of any reflections of it will give information on the location of any breaks in the fibre.

Referring to figures 20 to 25, the Head End and Customer End are shown in more detail. An important requirement of a communications system such as this, is that the Customer End keeps in time with the Head End.

Figures 20, 21 and 22 show the Customer Head End. A master clock of 20.0408MHz which corresponds to the bit rate through the system is phase locked to the incoming 2.048 MHz clock from the Head End Circuit Engine, which corresponds to a standard 32 channel TDM highway. BF (figure 22) and MF Sync signals are also generated and locked to the 8kHz framing signal from the Circuit Engine. A 2.304MHz bit clock is generated in order that the circuit engine can insert an additional bit per channel at the same frame rate into the basic frame in order to convert the bitrate into that required for the system.

In order that the Customer End keeps in 'time' with the Head End, data from the Head End is used to regenerate the clock pulses at the Customer end. The transition between 'zero'bits and 'one' bits are used for this purpose. The data from the Head End may, however, not have sufficient transitions for the clock regeneration. It is therefore necessary to scramble the data form the Head End using a pseudo random binary sequence (PRBS) to produce a data stream which is rich in transitions. Data from the Head End Circuit Engine is scrambled as shown in figure 21 using a $2^9 -1$ scrambling sequence.

The Sync frame (Fig 17) is also scrambled, using a different PRBS, and inserted into the scrambled data. The last 140 bits of the Sync frame (Fig 17), the MF Sync pattern are used to synchronise Customer End. Before scrambling, these 140 bits are 140 zero bits. Once scrambled, they form an easily identifiable pattern which may be used for OTDR to detect leaks, as previously mentioned.

It is very important that the Customer end correctly identifies the 140 bits MF Sync pattern. If there were a naturally occurring string of 140 zero bits within the

first 4748 bits of the Sync frame, the Customer End would wrongly identify the MF Sync Pattern. These 4748 bits are therefore deliberately perturbed after they have been scrambled, in order to introduce a known error. This is achieved by inverting every sixteenth bit, and ensures that the Customer End will not mis-identify the MF Sync pattern. The data may also be ciphered for security reasons.

Any data received at the Head End is returned and presented to the Circuit Engine:

Figure 22 shows the Head End Circuit Engine which has the task of interfacing up to 8 Network Adapter (NA) cards to the BTS. Each NA handles all the traffic from 2 MBit/s data stream (or equivalent). The outputs from all 8NA cards are frame aligned, and that all 2 MBit/s clocks are synchronous.

Reference 2.048MHz and 8kHz framing clocks are extracted from the NA inputs to phase lock the BTS 20.040MHz master clock. The BTS provides a common 2.304MHz bit clock to each NA to synchronise data transfer to and from the Circuit Engine.

Data is stored in Fifo buffers, and transmitted through the BTS via the transmit register. Control is provided here to ensure that only the minimum amount of data is stored in the Fifo buffer. This is important to keep a tight control of the transport delay through the BTS.

On the receive side, data received over the BTS is again stored in a Fifo buffer before being returned to the NA cards via the Output ports. Fifo contents control is again provided.

Referring to Figures 23, 24 and 25 the Customer End is shown in more detail.

A 20.0408 MHz clock is phase locked to the incoming scrambled data stream. This clocks all the receiver circuitry. The Sync frame from the Head End containing the BF and MF Sync patterns is descrambled and extracted to synchonise the receiver.

The broadcast data stream is then descrambled, and if it has been ciphered for security reasons, deciphered, and the resultant received data stream is fed to the Circuit Engine.

The transmit frame timing is offset by a specific number of clock cycles and the transmit clock phase is set in the Transmit Phase and Framing generator. The values to be used are provided by the House keeping extract unit. This permits precise adjustment of use, time and phase of arrival of Customer end transmitted data bit/s at the Head End.

A local 2.048 MHz clock is phase locked to the 20.0408 MHz clock, and this and an 8kHz framing clock are also fed to the circuit engine.

Figure 23 shows the Customer End Circuit Engine.

Specific single bits of data are snatched from the received data stream by the Data Snatcher, which interprets the start channel band bitrate information from the housekeeping block. The snatched data is stored in the Output Fifo buffer until output to the Customer end Network Adapter (CNA).

Control of the Fifo contents is provided by the Framing control block which ensures that the Fifo contents are kept to a minimum. Again this is necessary to minimise the transport delay thought the BTS.

Data is actually clocked in and out of the CNA using a clock derived by the CNA from a standard 2.048MHz and 8kHz clock pair provided by the BTS.

Data for transmission to the Head End of the BTS passes through a similar path, and is transmitted as discrete bits interleaved with traffic from other Customers Ends. (Such an approach allows the use of a cheaper laser diode in the Customer End transmitter).

One simple way to provide security is to physically prevent access to the signals. This may be achieved at the optical level, for example, by not providing a demountable connector, merely a permanent connection into a sealed unit which would not allow unauthorised access to timeslots from the 'outside world'. Figure 8 shows a possible transmission module option containing the BTS, optical transmit and optical receive circuitry together with an optical filter and coupler. A 'semi-permanent' optical connection on the line side of the module provides a good degree of security, whilst only authorised time slot data would be available on the electrical connections to the line circuit equipment. This may necessitate configuration data to be securely downloaded from the administration centre to remotely programme timeslot access. Other options include the incorporation of encryption algorithms, and the use of Personal Identification Numbers (PIN's) for user validation.

Two examples will now be described of simple experimental set-ups as illustrations of the present invention.

The arrangement of Figure 9 was used to illustrate the technical feasibility of the present invention. Referring to Figure 9, the illustrated arrangement includes:-

a) a power divider with sufficient stages to represent the loss of a 256 way split. This splitter is wavelength flattened to permit operation in the 1300nm and 1550nm windows;

b) bidirectional operation;

c) A synchronous TDMA optical network. Each remote terminal is locked to a master clock at the exchange and is allocated time slots for return channel signalling. Time slots are interleaved passively in the network;

d) Low duty-cycle signalling. Remote lasers are only required to transmit during the allocated time slots. (For the PMUX demonstration system described below the duty cycle is 1/64 per channel. This feature offers enhanced laser reliability and elimination of temperature control circuitry); and

e) automatic ranging. The synchronous network requires the use of a ranging protocol to allocate time slots to remote terminals. This protocol must take account of the round-trip delay and the availability of channels.

The first four of these features use commercially available primary multiplexers (PMUXs) as a basic system building block. PMUXs transmit 30 PCM channels plus frame alignment and signalling bits at 2.048 Mbit/s. The standard circuitry includes the audio A/D and D/A necessary for a telephone interface.

For both demonstrations construct optical transmitters and receivers for the respective transmission rates of 2 and 8 Mbit/s were used. The first demonstration is of a PMUX system using the configuration shown in Fig 10. Two types to PMUX were employed: a rack-mounted PMUX representing the local exchange, and several PMUX's representing individual customers. Telephones were connected to the PMUX's via interface boxes which provide DC power and 2 to 4 wire conversion.

In the downstream direction, 30 PCM channels of analogue telephony from the local exchange were

multiplexed onto a 2 Mbit/s digital output in HDB3 format (High Density Bipolar ternary code). This was used to directly modulate an IRW semiconductor laser (with mean power feedback control circuitry). The signal then passed through a fused taper coupler to separate the transmit and receive paths at the exchange end. All spare legs on all couplers were index matched to reduce the risk of reflections.

The signal then passed through 6 km of a single mode fibre to simulate the link to the cabinet. It was then distributed to the individual customers via a splitter, fabricated from wavelength flattened fused biconical tapers, which had a loss representing a 256-way splitting ratio. Four of the outputs from this splitter were connected to a further coupler to separate the receive and transmit paths at the customer's end.

Commercial PIN FET transimpedance receivers with a quoted minimum sensitivity of -52 dBm were mounted on a card designed to plug directly into the customer's PMUX. Each PMUX could receive all 30 channels, but only one channel was physically connected for each customer. After subsequent equalisation, this channel was demultiplexed and connected to the customer's telephone.

In the upstream direction, a different transmission format was employed, because of the need to interleave the individual customer's bytes (word interleaving) to form a 2 Mbit/s frame which could be received by the exchange PMUX. The conventional 2 Mbit/s digital output from the customer's PMUX could not therefore be used, so NRZ binary signals were picked directly off the backplane. A transmitter card was designed to do this which plugged directly into the PMUX. This included a laser as before, but operating in low duty-cycle mode without cooling, and an addressable digital delay line to move the customer's

channel by .5 bit intervals, enabling it to fit correctly into the 2 Mbit/s PCM frame when interleaved with other customer's channels. A total of 5 cards are required to equip a PMUX for up to 8 customers: power card, audio card, mux/control card, transmit card and receive card.

The output from the customer's laser in serial byte format was then passed through the customer's coupler again, back up through the splitter, through the fibre, and into the exchange receiver via the exchange coupler. The NRZ binary was then converted into HDB3 format, using a System X digital line interface card, for input to the GEC PMUX. This signal was converted to telephony via the audio interface as before. Autoranging was not implemented in this demonstration.

Figure 10 shows the experimental network. A two line System X exchange was employed. One line was a 'copper subscriber' using and NTI phone. The other line connected the 'network customer' via the fibre network, through to the exchange. Digital speech was transmitted in both directions simultaneously by calling between the copper and network subscribers.

Initially, a previously installed tube system was extended to provide a link across site via a standard cabinet. Wavelength flattened 2x2 splitters were mounted in terminal boxes at each end of the network to provide full duplex transmission capability. A 4x4 flattened array was mounted in the cabinet to model a street flexibility point. An additional 2x2 was mounted to simulate a distribution point (DP).

Index matching was performed on all unterminated fibre ends in the network to reduce crosstalk from back reflections. The link length was 1.5km.

A (TDM) time domain multiplex broadcast system was used for downstream communication from head end to

subscriber. The data stream is continuous with any unused frames packed with PRBS. Conventional AC coupled laser transmitter and optical receivers were appropriate. The laser launched -8.5 dBm into the fibre at 1300nm. A 2 Mb/s optical modem was modified to provide the receiver stage. Receiver sensitivity was measured at -30 dbm.

In the upstream direction transmission is by TDMA with each outstation sending packets of data in assigned time slots. In this case DC coupled optical transmitters and receivers were used. Each customer transmitter was turned fully off when no data was being sent to avoid inter-channel interference on the shared fibre. This was achieved by biasing the laser off, turning it fully on for a logic 'one' and turning it fully off again for a logic 'zero'. This differs from conventional point to point fibre systems in which the transmitter is biased above turn-on and modulated about that point.

The optical receiver is also designed to operate in the presence of a burst mode signal. A DC coupled receiver is required to avoid baseline drift in the absence of received data during the quiet period between packets. The receiver used was based on a long wavelength InGaAs PIN photodiode operating into a high input impedance FET op-amp, with bootstrap feedback to reduce input capacitance.

A ranging function is required at the subscribers terminal to ensure that packets are transmitted at the correct instant to avoid time overlap at the head end.

The preferred arrangement for a full network is to have 15 exchange lines at the DP, with 1 to 15 exchange lines interfaces per customer optical termination, a two level optical split hierarchy (nominally at cabinet and DP sites) with a distance of about 1.6km between exchange and cabinet, 500m between cabinet and DP and each customer.

It will be appreciated that different distances between exchange and cabinet and from cabinet to customer are possible as well as a split hierachy greater than 2, the former extending to perhaps 200 km and the latter to 2km (or down to 5m when the DP is of a customer site). These distances are largely dictated by the geographical distribution of the customers relative to a central station or exchange.

If a copper wire is made to some customers from the network a single level optical split hierarchy is preferred, nominally sited at the cabinet.

Although a conventional exchange to cabinet distance of 1.6km has been assumed, the system will be capable of much greater ranges of at least 10km. This can provide a basis for rationalising the number of local exchanges in a given Network. The efficient multiplexing structure of such a network (arising from the combination of optical splitting and the sharing of the customer's optical connection cost over multiple lines) should mean that the enhanced upper network costs associated with the longer links are kept within bounds. This should allow any significant cost savings identified for exchange rationalisation to be enjoyed to the full.

The passive network architecture offered by the present invention presents an opportunity for evolution towards a broadband multiservice network. When considering the evolution to broadband service capability two important principles need to be adhered to as far as possible. They are: (a) the need to minimise the cost of any additional features that are required on the initial network in order to allow graceful evolution to a multiservice broadband network and (b) to be able to add broadband services to an existing system without disturbing the basic telephony customers already connected.

An important consideration for the broadband network is the amount of extra field plant and installation work that will be required to add the new services. The aim here must be to minimise such costs by utilising as much as possible of the installed system base.

Expansion of the system to carry higher bit rate services such as cable television requires the use of wavelength division multiplexing (WDM) techniques unless the bit rate is sufficiently large at the outset to allow for future broadband service. The latter would load the costs of the initial basic services to an unacceptable degree and the introduction of broadband service must, at minimum, depend on the addition of at least one wavelength, allowing the existing narrowband customers to continue undisturbed in low bit rate mode. Because broadband services require higher bit rates than the low speed data and speech services the optical receiver sensitivities will be considerably reduced. This implies that the optical splitting radio used will be too large for the optical power budget available for the broadband services. It follows therefore that different access points will need to be available for the feeder fibres, carrying the broadband services from the head end, into the optical splitter array.

A bi-directional optical branching network with two stages of splitting can have a service upgrade by providing additional fibre from the exchange to the first splitting point and connecting in at different levels within this splitter. Although the bi-directional network has received the greatest attention so far, other structures are possible within the passive optical network concept of the applicant's invention and some of these may have advantages either in an initial telephony realisation or in the evolution of broadband services. For example,

the telephony could be two undirectional networks respectively carrying "go" and "return" channels to gain the benefits of lower transmission losses and avoiding reflection problems or it could have a single stage of splitting as described above in relation to Figure 4.

The evolution of the optical technology and the service package carried by an enhanced network are obviously closely coupled. For example the number of wavelengths available for broadband upgrade will depend crucially on the optical technology invoked. The technology available for optical wavelength multiplexing can be crudely divided into three categories of sophistication with many permutations in between (a more detailed breakdown of possible optical technology evolution and service packages is illustrated in Figure 11.

a. Fabry-Perot (F-P) lasers used with fixed wavelength filters for wavelength selection.

b. Single longitudinal mode lasers (eg. DFB) with tunable optical filters 18 and possibly early heterodyne optical receivers for wavelength selection.

c. Advanced coherent optical sources with combinations of optical filters (tunable) and electrical (heterodyne) techniques for channel selection.

The production tolerances of the fixed wavelength filters and the center wavelengths and line widths of the F-P laser sources would mean that technology category (a) would limit the number of wavelengths available to between 6 and 12 wavelengths over both windows of the fibre. In the customer to exchange direction where temperature control of the laser sources might be prohibitively expensive the number of wavelengths available could be limited to between 2 and 4 over both windows.

With the technology (b) the numbers of potential wavelengths could be considerably greater with maybe as many as one to two hundred being possible in the exchange to customer direction in the longer term. However it may well be that practical considerations such as the size of split or safety issues would limit the size of the wavelength multiplex before the optical technology did so. Even in the upstream direction, without any means of wavelength drift correction, 10 - 50 channels could be available.

Where the coherent technology (c) is used many hundreds of wavelengths are possible in principle, the limitations being imposed by non-linear phenomena in the fibres. With the large number of wavelength channels and the potentially large optical power budgets available, this technology would offer a further major reappraisal of the operating topologies for optical networks.

Technology (a) is available now (b) being possible in the two to five year time scale and (c) maybe being available within the decade at commercially acceptable prices within the decade.

Wavelength multiplexing will be the method for introducing broadband services into network and the following are examples of how the bidirectional branching network with two stages of splitting might evolve described with reference to Figures 12 go 14.

Fig 12 shows an initial network using a single wavelength to provide telephony/data services. The narrow pass optical filter at the customer's equipment allows the passage of only the initial wavelength for narrow band services, thus blocking interfering channels from (and unauthorised access to) broadband services added at a later stage. Another key provision for wideband service is the installation at the outset of a multi-stage cabinet

splitter which operates over a broad optical bandwidth in both 1300 and 1500 windows. This facilitates partial bypass by wideband service feeder fibres between the exchange and cabinet (see below). These extra fibres may be installed either within the cable or separately at a later date.

Figure 13 show additional wavelengths can be used to add new services eg. cable TV (CATV) to the network without disruption to the telephony service. The extra wavelengths are carried to the cabinet via additional feeder fibres and are fed into the network at space inputs to the cabinet splitter. The additional wavelengths will in general carry a higher bitrate than the telephony and ISDN channels. To accommodate the reduced receiver sensitivity incurred by the higher transmission bitrate, the fibre could bypass part of the cabinet splitter to reduce the optical path loss between the exchange/head end and the customers equipment. Customers destined to receive the additional broadband services would be equipped with a simple wavelength demultiplexer to separate the broadband and narrowband wavelengths.

Each additional wavelength, multiplexed onto a common fibre between the exchange and cabinet, could carry a CATV digital multiplex at say 565 Mb/s. This allows 16x70Mb/s or 8x140Mb/s channels to be broadcast per extra wavelength, over that sector of the network. At this bitrate the optical split could be limited to 32 ways compared with say 128 for the telephony optical split. However the addition of only one or two extra optical wavelengths could provide a CATV service delivering 16 to 32 channels on the basic optical telephony network. This would require very few additional optical components - i.e. broadband optical transmitters and wavelength multiplexer at the exchange; wavelength demultiplexer and

broadband receiver(s) at each customer terminal.

Additional wavelengths provided in this way give rise to an important choice for the operation of the CATV services:

The customers could access any of the broadcast wavelengths via a tuneable optical filter incorporated into their terminal equipment. This would allow simultaneous reception of several channels chosen from the electrical multiplex of 8 or 16 channels carried on the selected wavelength. Simultaneous reception of more than one optical wavelength would require additional optical filtering and an optical receiver for each additional wavelength selected. However, $100^{o}/o$ penetration of a service offering any number of simultaneous channels (up to the total number transmitted on a feeder fibre) to each customer could be achieved in this way.

Alternatively the number of CATV channels made available by the combination of WDM and TDM could be enough to allow one or more dedicated video channels to be assigned to each CATV customer. In this case the network operates as a star with the switch sited centrally at the exchange. This system would use as fixed wavelength demultiplexer and one optical receiver in the customer's equipment. Although this might simplify the customer equipment it could mean a compromise between service penetration and number of simultaneous channels received by the customers. For example if the combination of WDM and TDM allowed 32 channels to be transmitted on each feeder fibre and a 32 way optical split could be achieved, then 1 channel per customer could be allocated on a $100^{o}/o$ penetration basis. If however 4 channels per customer were required then a penetration of only $25^{o}/o$ would be available unless extra wavelengths could be provided to deliver more channels.

A more advanced stage using DFB lasers is illustrated in Fig. 14 will allow, the allocation of at least one dedicated wavelength per customer. For example, with say 12 to 32 wavelengths available on a 32 way split it would be possible to allocate each CATV customer with one wavelength to carry all the required broadband services eg. CATV, HDTV etc. The smaller number of wavelengths would limit penetration to 40°/o but as the number of wavelengths approached 32, 100°/o penetration could be achieved.

Rather than simply dedicating the wavelengths to individual subscribers there is also at this stage the opportunity of using tunable optical filters at the subscribers' premises as a broadband switching stage. This could significantly simplify the exchange switching of disparate broadband services (eg mixtures of broadcast and dedicated services from multiple sources could be multiplexed onto different optical wavelengths and be selected by the customer equipment).

For each of the technology stages described the number of wavelengths that are possible depends critically on the tolerancing and stability of the lasers, filters and the useable bandwidth of the fibre and couplers. Low cost narrowband services such as telephony and ISDN may necessarily operate without temperature stabilisation in customers terminals which could mean significant wavelength drifting of the customers lasers. Hence if schemes such as those shown in Fig 2 to 7 are used, large channel spacings would be necessary for services in the customer to exchange direction of transmission. Closer spacing would be possible in the exchange to customer direction by using temperature controlled sources at the exchange and tunable filters within the customers equipment to eliminate filter centre wavelength tolerances.

CLAIMS

1. An optical communications network comprising a central station, a plurality of outstations, and a branch network of waveguides comprising a single waveguide from said central station which carries, in use, time or frequency division multiplexed optical signals for said outstations, and one or more passive splitters to distribute optical power from said waveguide to two or more secondary waveguides for onward transmission to said outstations, said network being adapted for return signals from said outstations to be passively multiplexed onto said single waveguide, or a similar single waveguide.

2. A network as claimed in claim 1 in which all components of the network are operable at a fixed optical loss criterion corresponding to a predetermined maximum split independently of the actual split of the network, said actual split being less than said maximum split.

3. A network as claimed in claim 1 or claim 2 including an active electronic node adapted to transform electrical signals from least one outstation into a return optical signals.

4. A network as claimed in any preceding claim wherein said return signals are time division multiplexed.

5. A network as claimed in claim 5 in which the central station has a ranging means for detecting the temporal position of the signals from the outstations within a predetermined multiplex frame period which is responsive to any deviation of the positions from desired positions to send correction signals to the outstations, the outstations including a variable delay means and being responsive to the correction signals addressed to it by

the central station to vary the variable delay whereby the return signals are passively multiplexed at the correct frame positions.

6. A network as claimed in any preceding wherein signals from at least 15 outstations are multiplexed on said single waveguide.

7. A network as claimed in any preceding claim, wherein said waveguides are single mode optical fibres.

8. A network as claimed in any preceding claim, wherein the length of said single waveguide is in the range 2 to 200 km.

9. A network as claimed in any preceding claim, wherein said length of said single waveguide is in the range 5 to 25 km.

10. A network as claimed in any preceding claim, wherein the power of signals from said single waveguide is passively split for onward transmission along between 4 and 128 secondary waveguides.

11. A network as claimed in Claim 10, wherein the length of said further waveguides is between 5m and 2km.

12. A network as claimed in Claim 10 and Claim 11 wherein the power of signals from said secondary waveguides is passively split for onward transmission along between 4 and 64 tertiary waveguides.

13. A network as claimed in any preceding claim wherein said splitter comprises an array of optical couplers.

14. A network as claimed in any preceding claim, wherein the bit rate of the multiplexed signals on the single waveguide is above 1 Mbit/s.

15. A network as claimed in any preceding claim, wherein the bit rate of the multiplexed signals on the single waveguide is between 2 Mbit/s and 5 Gbit/s.

16. A network as claimed in any preceding claim,

comprising filter means associated with each outstation so then the bandwidth received by each outstation lies on the range 32 kbit/s to 2 Mbit/s.

17. A network as claimed in any preceding claim, comprising filter means associated with each outstation so that the bandwidth of time or frequency division multiplexed signals received by each outstation lies in the range 64 kbit/s to 256 kbit/s.

18. A network as claimed in any preceding claim adapted for carrying telephony traffic and associated signalling information.

19. A network as claimed in Claim 18, wherein said traffic is carried on a single time division multiplexed channel.

20. A network as derived in Claim 19, adapted to carry, additionally, broadband services on further channels on different wavelengths.

21. A network as claimed in any preceding claim in which the optical signals from the central station are at a carrier wavelength different from the optical signals from the outstations.

22. A network as claimed in any preceding claim in which the branch network of waveguides carrying optical signals from the central station to the outstations has no common waveguide with the branch network of waveguides carrying optical signals form the outstations to the central station

23. A network as claimed in any preceding claim including an optical coupling means arranged such that two or more optical signals can be coupled to the single fibre for distribution to the outstations.

Fig. 1

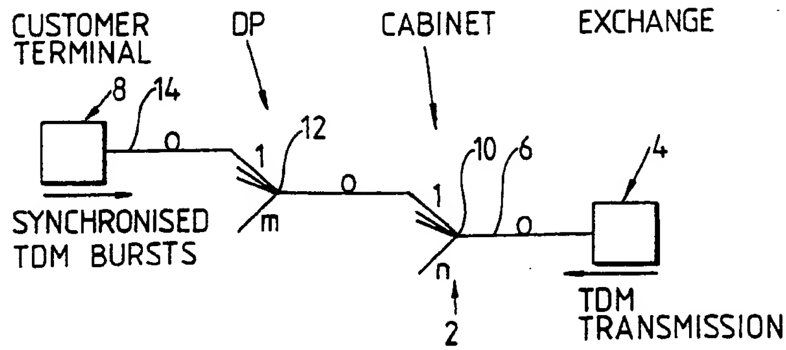


Fig. 2

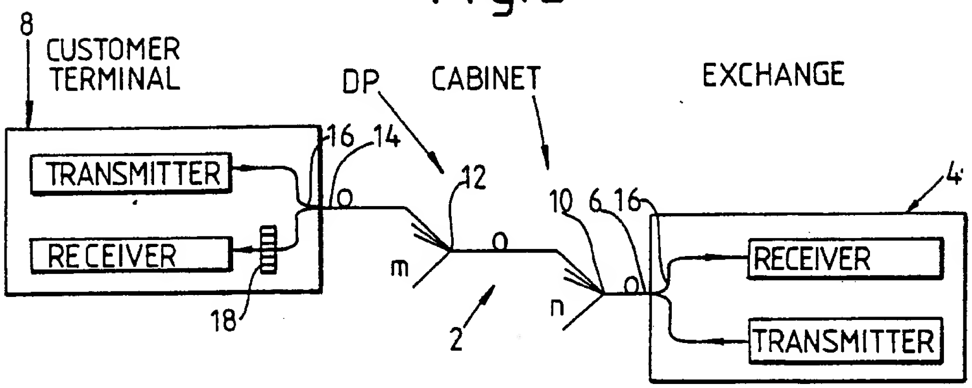


Fig. 3

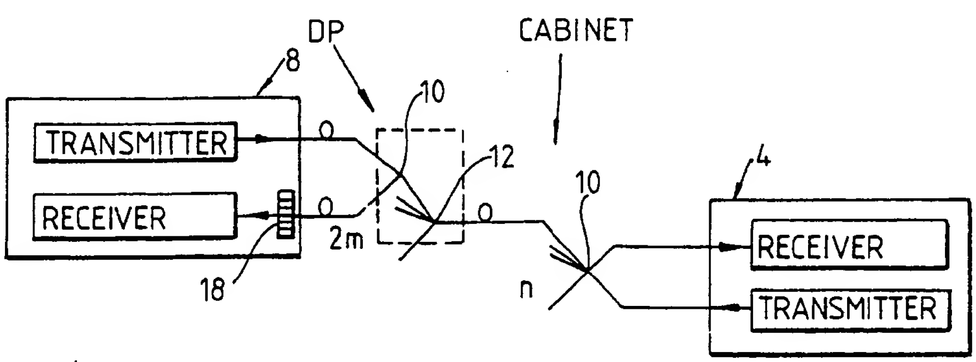


Fig. 4

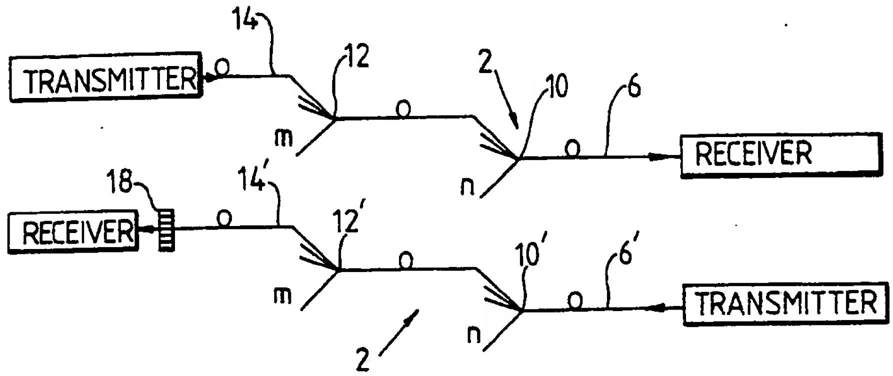


Fig.5

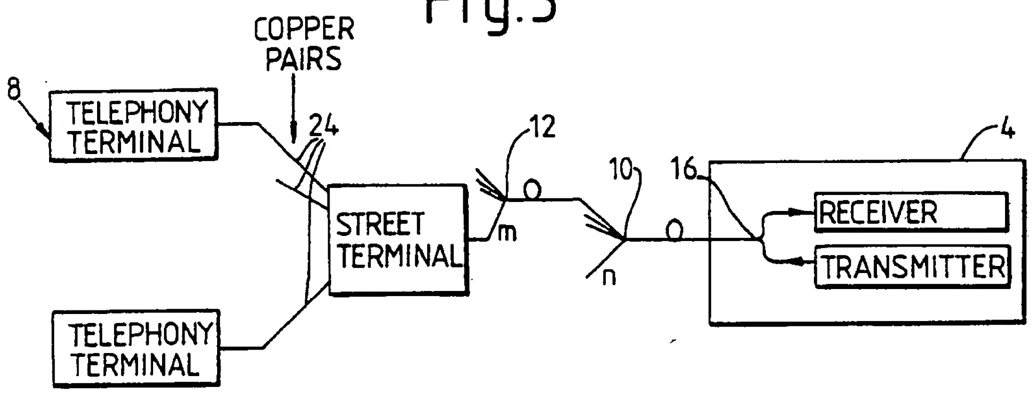


Fig.6

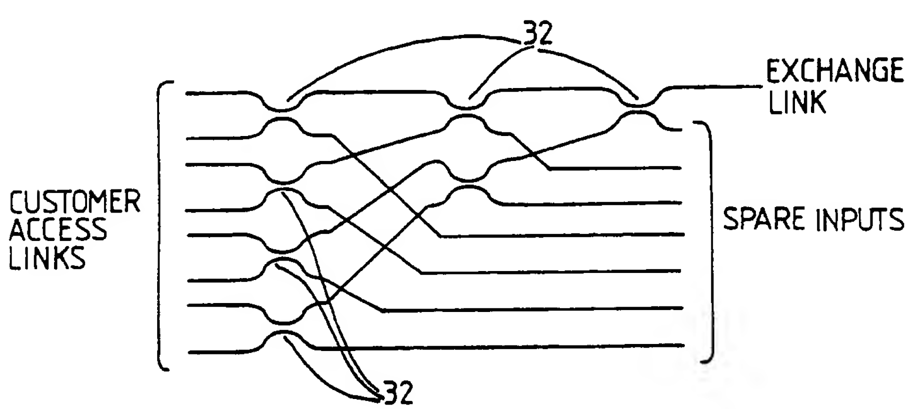


Fig.7

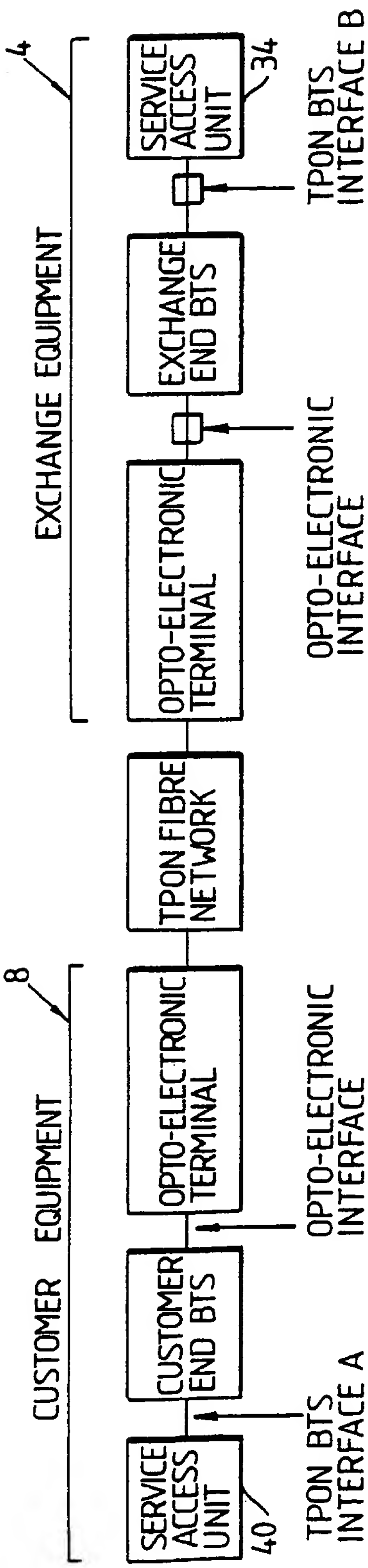

CUSTOMER EQUIPMENT
8
EXCHANGE EQUIPMENT
4
SERVICE ACCESS UNIT
40
CUSTOMER END BTS
OPTO-ELECTRONIC TERMINAL
TPON FIBRE NETWORK
OPTO-ELECTRONIC TERMINAL
EXCHANGE END BTS
SERVICE ACCESS UNIT
34
TPON BTS INTERFACE A
OPTO-ELECTRONIC INTERFACE
OPTO-ELECTRONIC INTERFACE
TPON BTS INTERFACE B

Fig.12

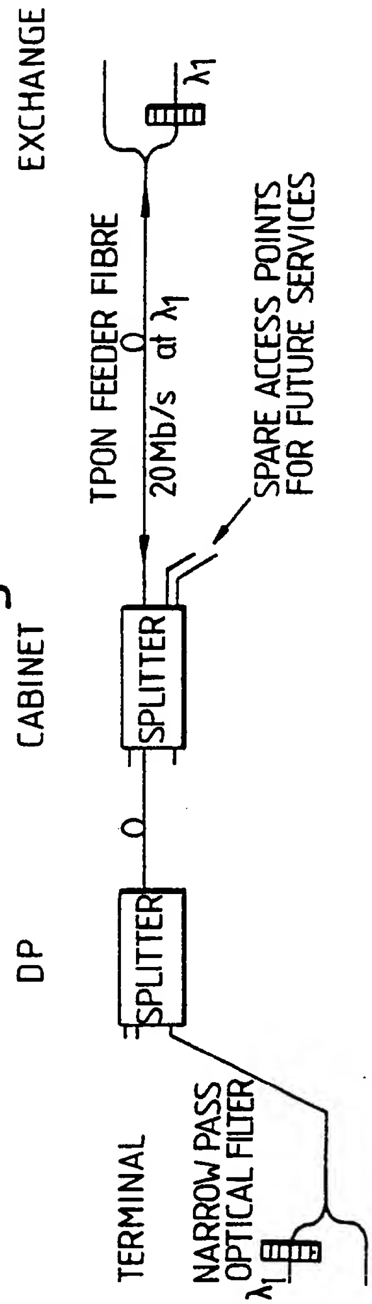

TERMINAL
DP
CABINET
EXCHANGE
NARROW PASS OPTICAL FILTER
SPLITTER
SPLITTER
TPON FEEDER FIBRE
20Mb/s at λ1
SPARE ACCESS POINTS FOR FUTURE SERVICES

Fig. 8

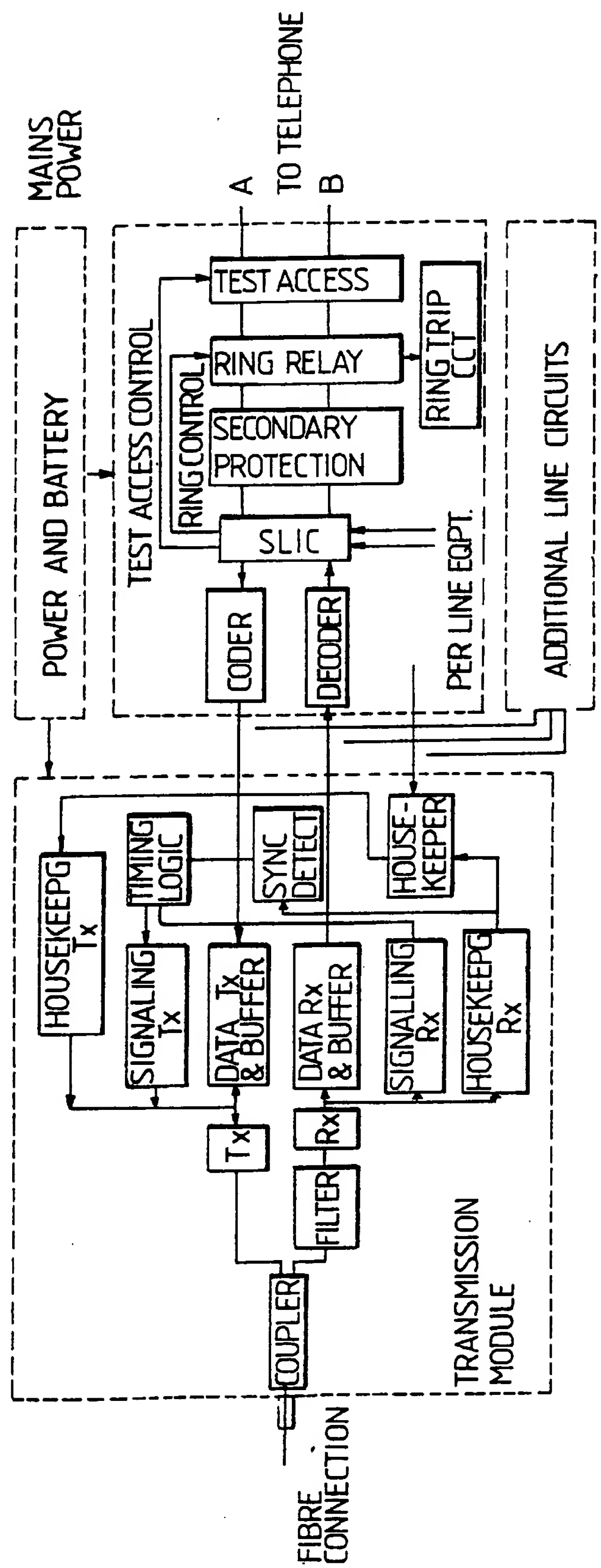

MAINS POWER
TO TELEPHONE
A
B
POWER AND BATTERY
TEST ACCESS CONTROL
RING CONTROL
TEST ACCESS
RING RELAY
RING TRIP CCT
SECONDARY PROTECTION
SLIC
CODER
DECODER
PER LINE EQPT.
ADDITIONAL LINE CIRCUITS
HOUSEKEEPG Tx
TIMING LOGIC
SYNC DETECT
HOUSE-KEEPER
SIGNALING Tx
DATA Tx & BUFFER
DATA Rx & BUFFER
SIGNALLING Rx
HOUSEKEEPG Rx
Tx
Rx
FILTER
COUPLER
TRANSMISSION MODULE
FIBRE CONNECTION

Fig. 9

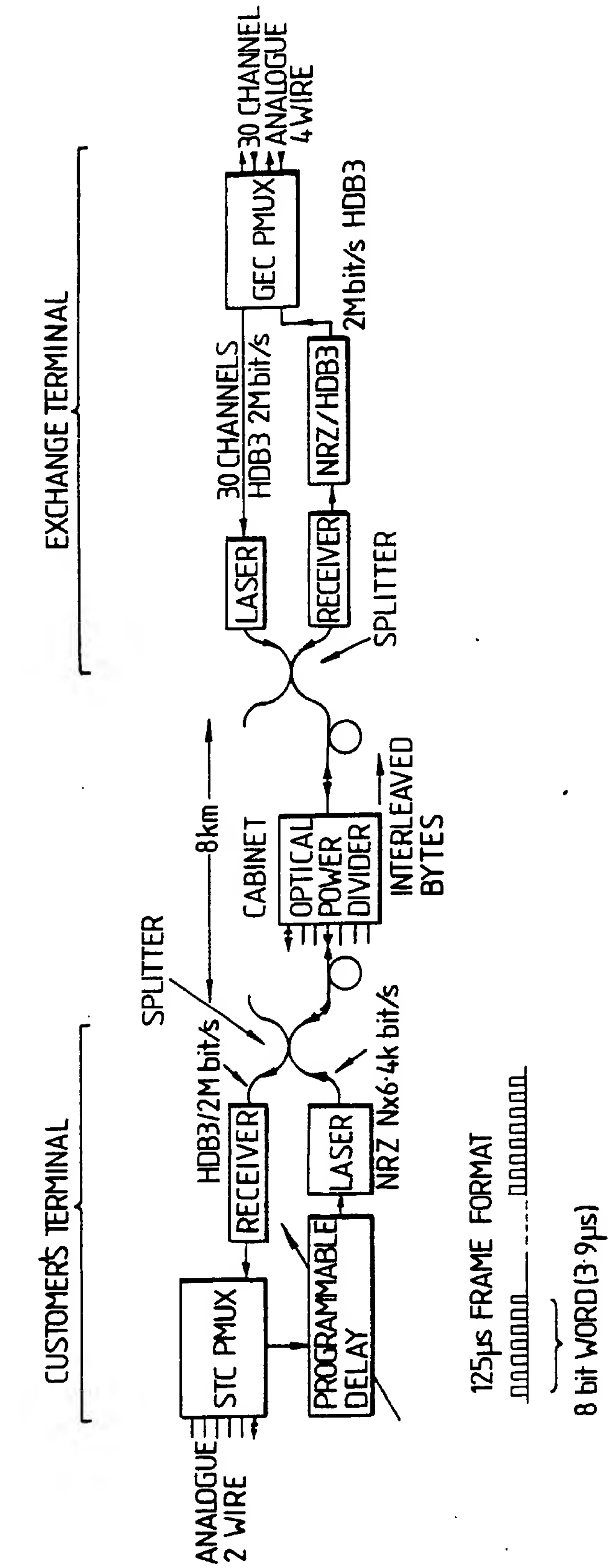

EXCHANGE TERMINAL
30 CHANNEL
ANALOGUE
4 WIRE
GEC PMUX
2Mbit/s HDB3
30 CHANNELS
HDB3 2Mbit/s
NRZ/HDB3
LASER
RECEIVER
SPLITTER
8km
CABINET
OPTICAL
POWER
DIVIDER
INTERLEAVED
BYTES
SPLITTER
HDB3/2M bit/s
NRZ Nx6·4k bit/s
CUSTOMER'S TERMINAL
RECEIVER
LASER
STC PMUX
PROGRAMMABLE
DELAY
ANALOGUE
2 WIRE
125µs FRAME FORMAT
8 bit WORD (3·9µs)

Fig.10

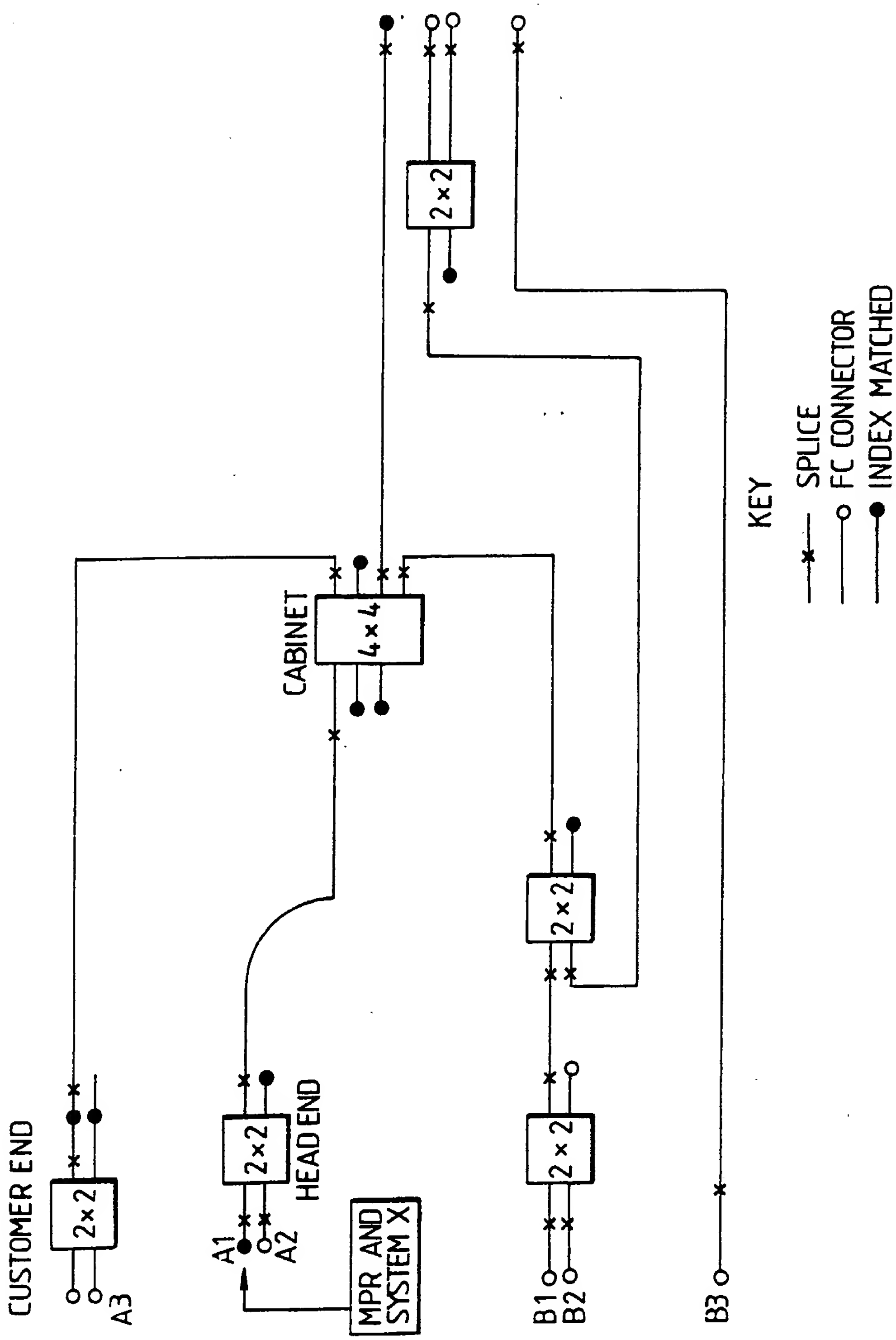

CUSTOMER END
2×2
A3
A1
A2
2×2
HEAD END
MPR AND
SYSTEM X
CABINET
4×4
2×2
2×2
2×2
B1
B2
B3
KEY
SPLICE
FC CONNECTOR
INDEX MATCHED

Fig.11

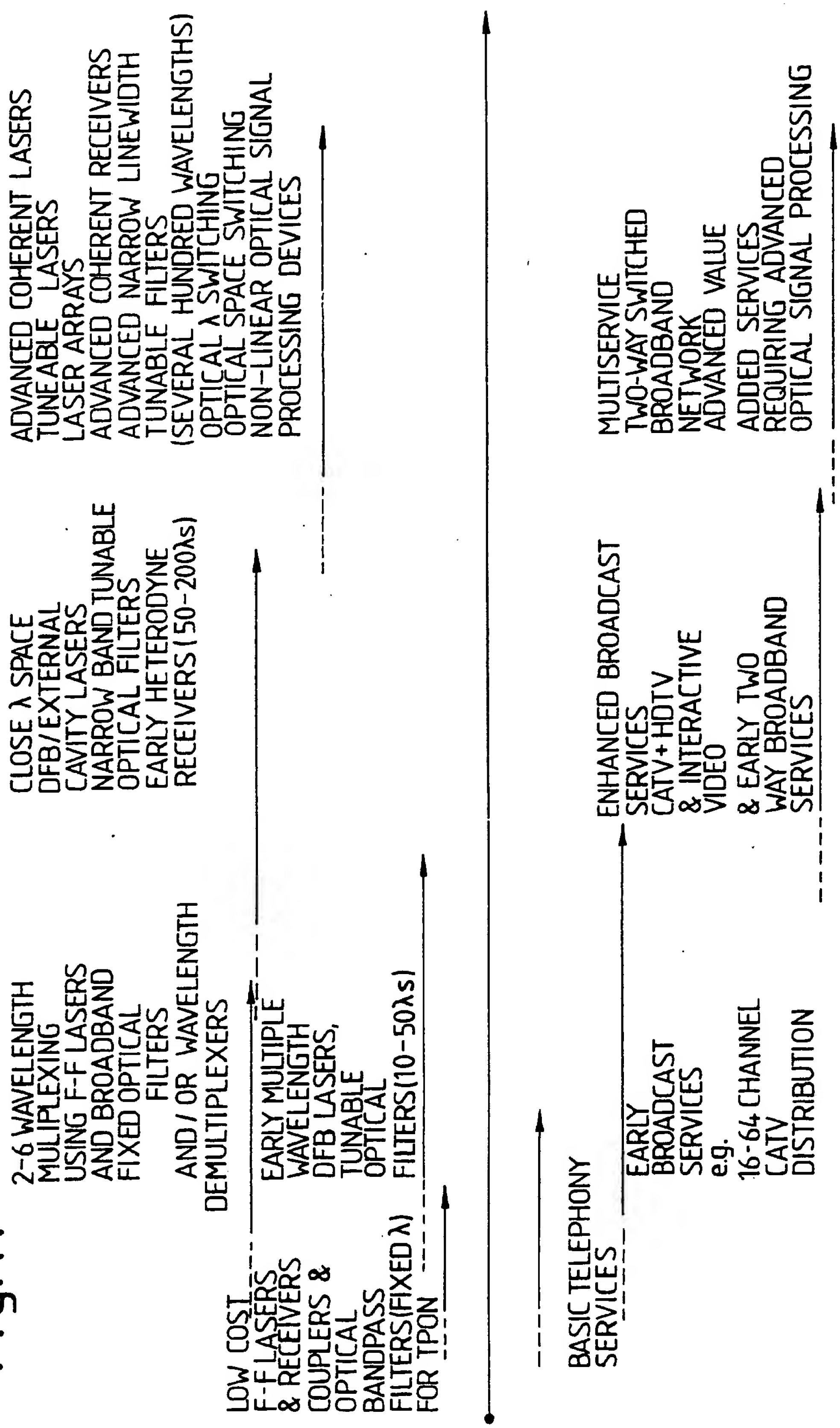

LOW COST F-F LASERS & RECEIVERS COUPLERS & OPTICAL BANDPASS FILTERS (FIXED λ) FOR TPON
2-6 WAVELENGTH MULIPLEXING USING F-F LASERS AND BROADBAND FIXED OPTICAL FILTERS AND / OR WAVELENGTH DEMULTIPLEXERS
EARLY MULTIPLE WAVELENGTH DFB LASERS, TUNABLE OPTICAL FILTERS (10-50λs)
CLOSE λ SPACE DFB/EXTERNAL CAVITY LASERS NARROW BAND TUNABLE OPTICAL FILTERS EARLY HETERODYNE RECEIVERS (50-200λs)
ADVANCED COHERENT LASERS TUNEABLE LASERS LASER ARRAYS ADVANCED COHERENT RECEIVERS ADVANCED NARROW LINEWIDTH TUNABLE FILTERS (SEVERAL HUNDRED WAVELENGTHS) OPTICAL λ SWITCHING OPTICAL SPACE SWITCHING NON-LINEAR OPTICAL SIGNAL PROCESSING DEVICES
BASIC TELEPHONY SERVICES
EARLY BROADCAST SERVICES e.g. 16-64 CHANNEL CATV DISTRIBUTION
ENHANCED BROADCAST SERVICES CATV+HDTV & INTERACTIVE VIDEO & EARLY TWO WAY BROADBAND SERVICES
MULTISERVICE TWO-WAY SWITCHED BROADBAND NETWORK ADVANCED VALUE ADDED SERVICES REQUIRING ADVANCED OPTICAL SIGNAL PROCESSING

Fig.13

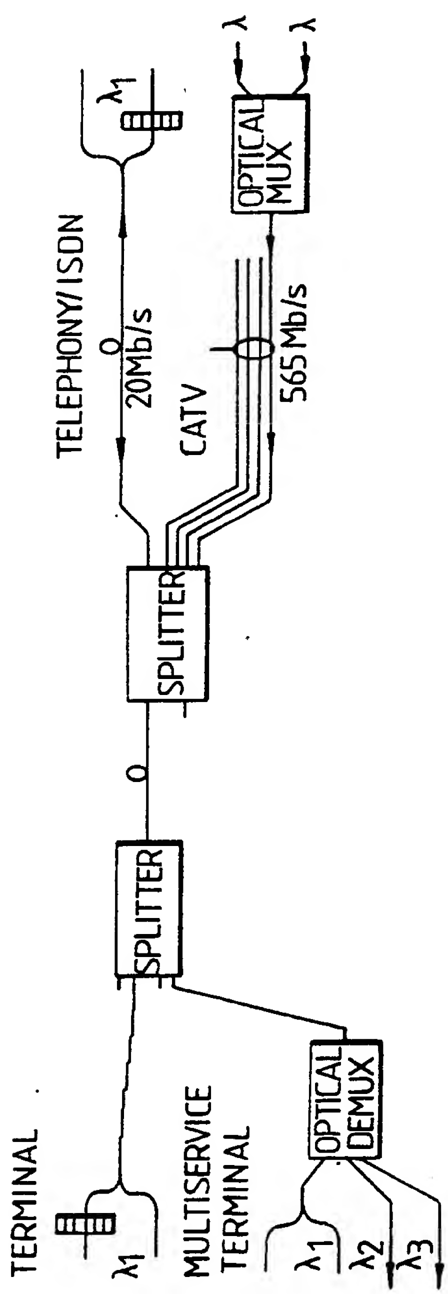

TELEPHONY/ISDN
20Mb/s
CATV
565 Mb/s
SPLITTER
SPLITTER
OPTICAL MUX
TERMINAL
MULTISERVICE TERMINAL
OPTICAL DEMUX
λ_1
λ_1
λ_1
λ_2
λ_3
λ
λ

Fig.14

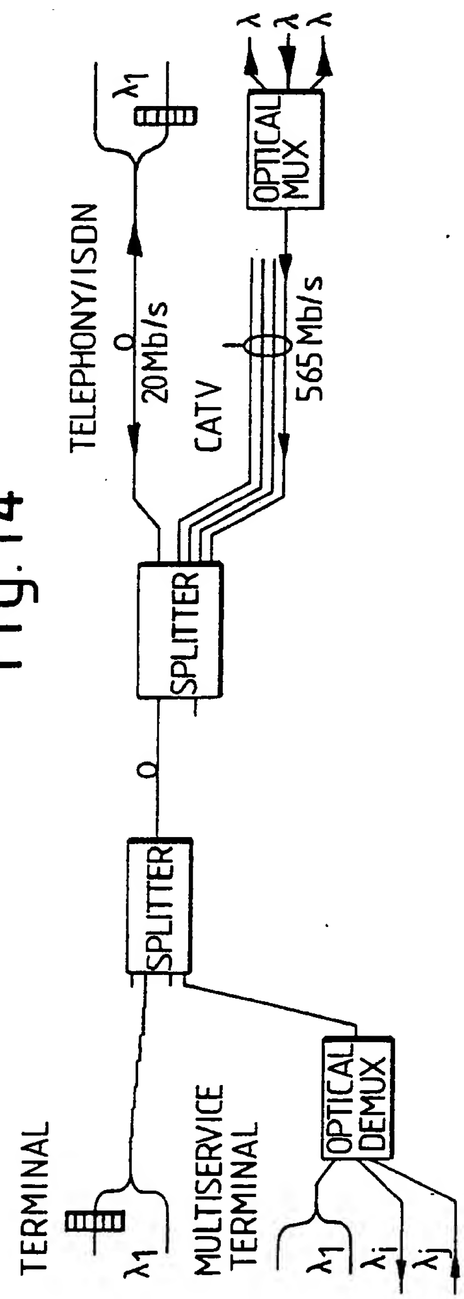

TELEPHONY/ISDN
20Mb/s
CATV
565 Mb/s
SPLITTER
SPLITTER
OPTICAL MUX
TERMINAL
MULTISERVICE TERMINAL
OPTICAL DEMUX
λ_1
λ_1
λ_1
λ_i
λ_j
λ
λ
λ

Fig.15

BASIC FRAME

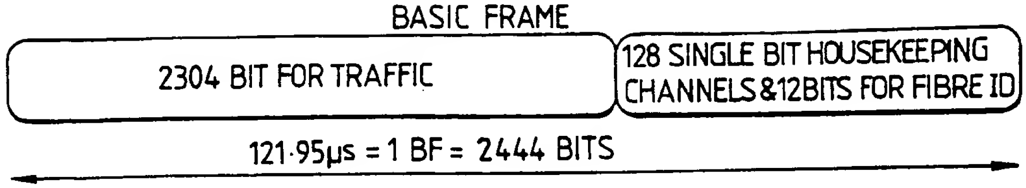


Fig.16

MULTI–FRAME

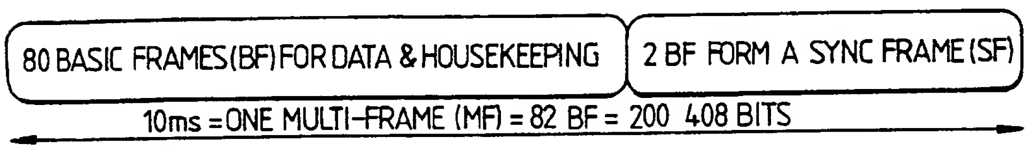


Fig.17

SYNC FRAME FROM HEAD END

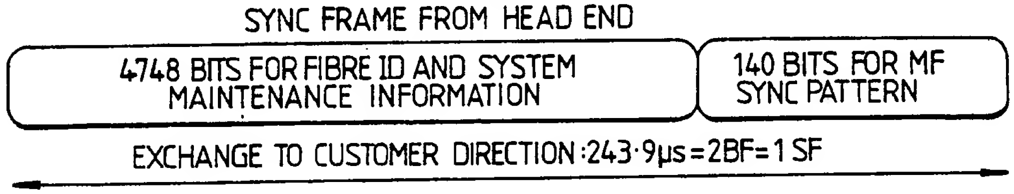


Fig.18

SYNC FRAME FROM CUSTOMER END

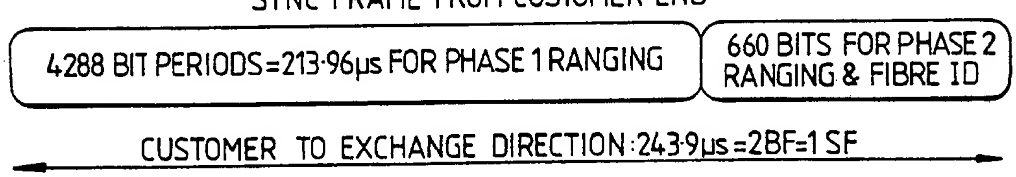


Fig.19

RANGING FROM CUSTOMER END

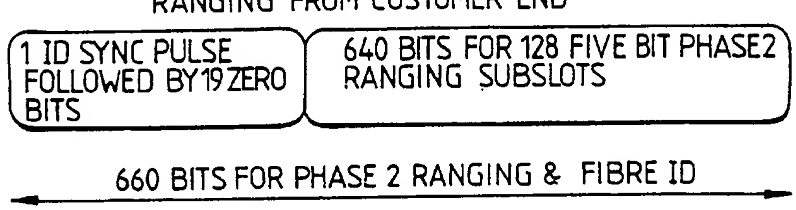


Fig. 20

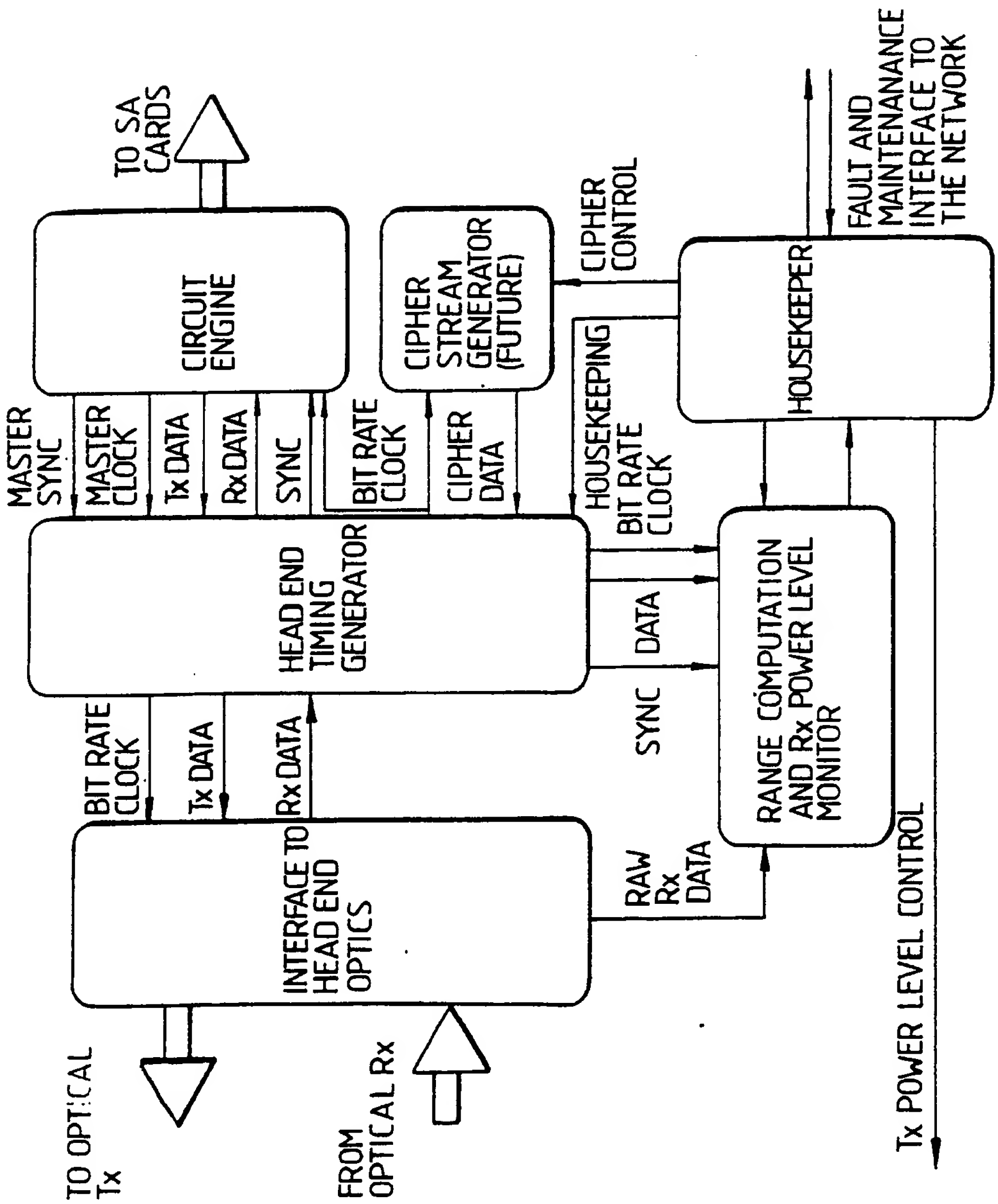

TO SA CARDS
CIRCUIT ENGINE
CIPHER STREAM GENERATOR (FUTURE)
CIPHER CONTROL
HOUSEKEEPER
FAULT AND MAINTENANANCE INTERFACE TO THE NETWORK
MASTER SYNC
MASTER CLOCK
Tx DATA
Rx DATA
SYNC
BIT RATE CLOCK
CIPHER DATA
HOUSEKEEPING
BIT RATE CLOCK
HEAD END TIMING GENERATOR
DATA
SYNC
RANGE COMPUTATION AND Rx POWER LEVEL MONITOR
BIT RATE CLOCK
Tx DATA
Rx DATA
INTERFACE TO HEAD END OPTICS
RAW Rx DATA
TO OPTICAL Tx
FROM OPTICAL Rx
Tx POWER LEVEL CONTROL

Fig. 21

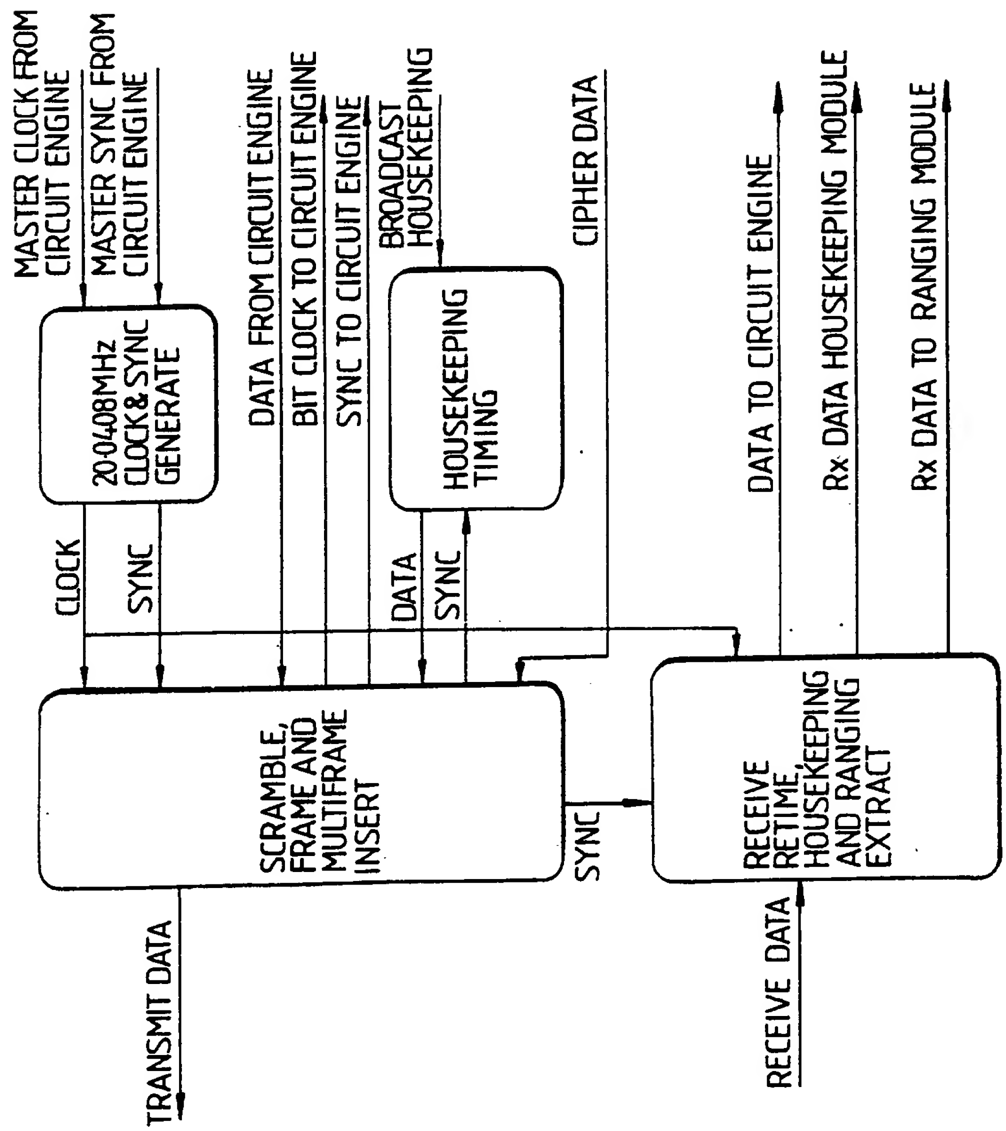

MASTER CLOCK FROM CIRCUIT ENGINE
MASTER SYNC FROM CIRCUIT ENGINE
20·0408MHz CLOCK & SYNC GENERATE
CLOCK
SYNC
DATA FROM CIRCUIT ENGINE
BIT CLOCK TO CIRCUIT ENGINE
SYNC TO CIRCUIT ENGINE
BROADCAST HOUSEKEEPING
HOUSEKEEPING TIMING
DATA
SYNC
CIPHER DATA
SCRAMBLE, FRAME AND MULTIFRAME INSERT
TRANSMIT DATA
SYNC
RECEIVE RETIME, HOUSEKEEPING AND RANGING EXTRACT
RECEIVE DATA
DATA TO CIRCUIT ENGINE
Rx DATA HOUSEKEEPING MODULE
Rx DATA TO RANGING MODULE

Fig.22

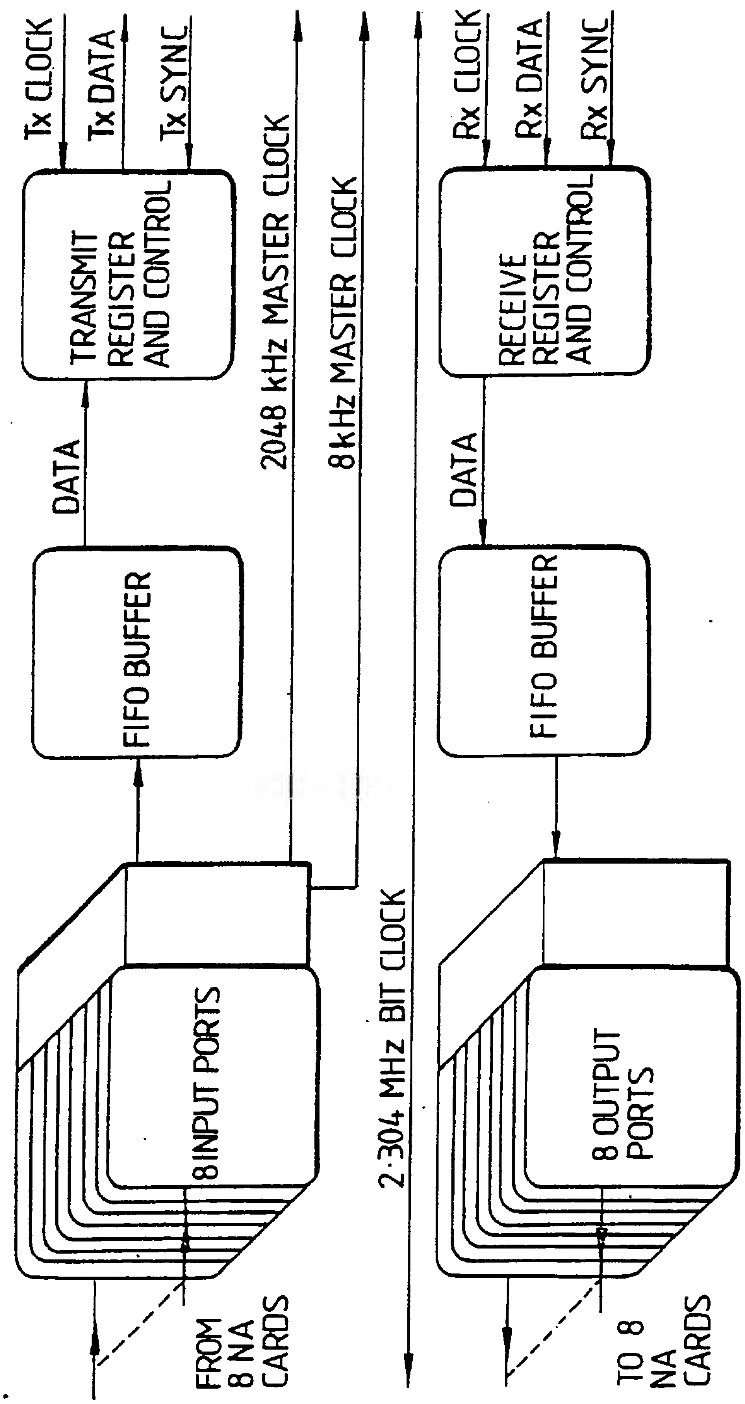
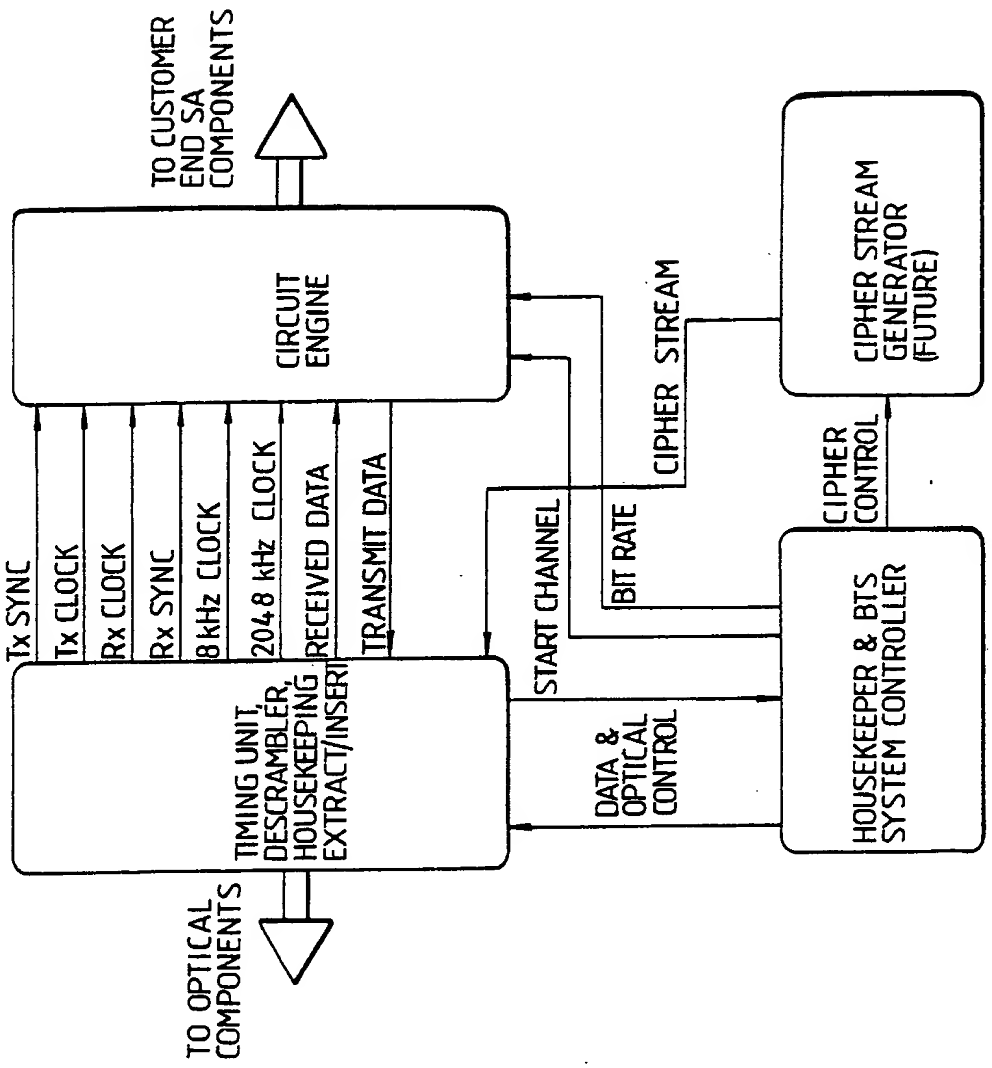

Tx CLOCK
Tx DATA
Tx SYNC
TRANSMIT REGISTER AND CONTROL
DATA
FIFO BUFFER
8 INPUT PORTS
FROM 8 NA CARDS
2048 kHz MASTER CLOCK
8 kHz MASTER CLOCK
2·304 MHz BIT CLOCK
Rx CLOCK
Rx DATA
Rx SYNC
RECEIVE REGISTER AND CONTROL
DATA
FIFO BUFFER
8 OUTPUT PORTS
TO 8 NA CARDS

Fig. 23


TO CUSTOMER END SA COMPONENTS
CIRCUIT ENGINE
CIPHER STREAM
CIPHER STREAM GENERATOR (FUTURE)
CIPHER CONTROL
Tx SYNC
Tx CLOCK
Rx CLOCK
Rx SYNC
8 kHz CLOCK
2048 kHz CLOCK
RECEIVED DATA
TRANSMIT DATA
START CHANNEL
BIT RATE
TIMING UNIT, DESCRAMBLER, HOUSEKEEPING EXTRACT/INSERT
DATA & OPTICAL CONTROL
HOUSEKEEPER & BTS SYSTEM CONTROLLER
TO OPTICAL COMPONENTS

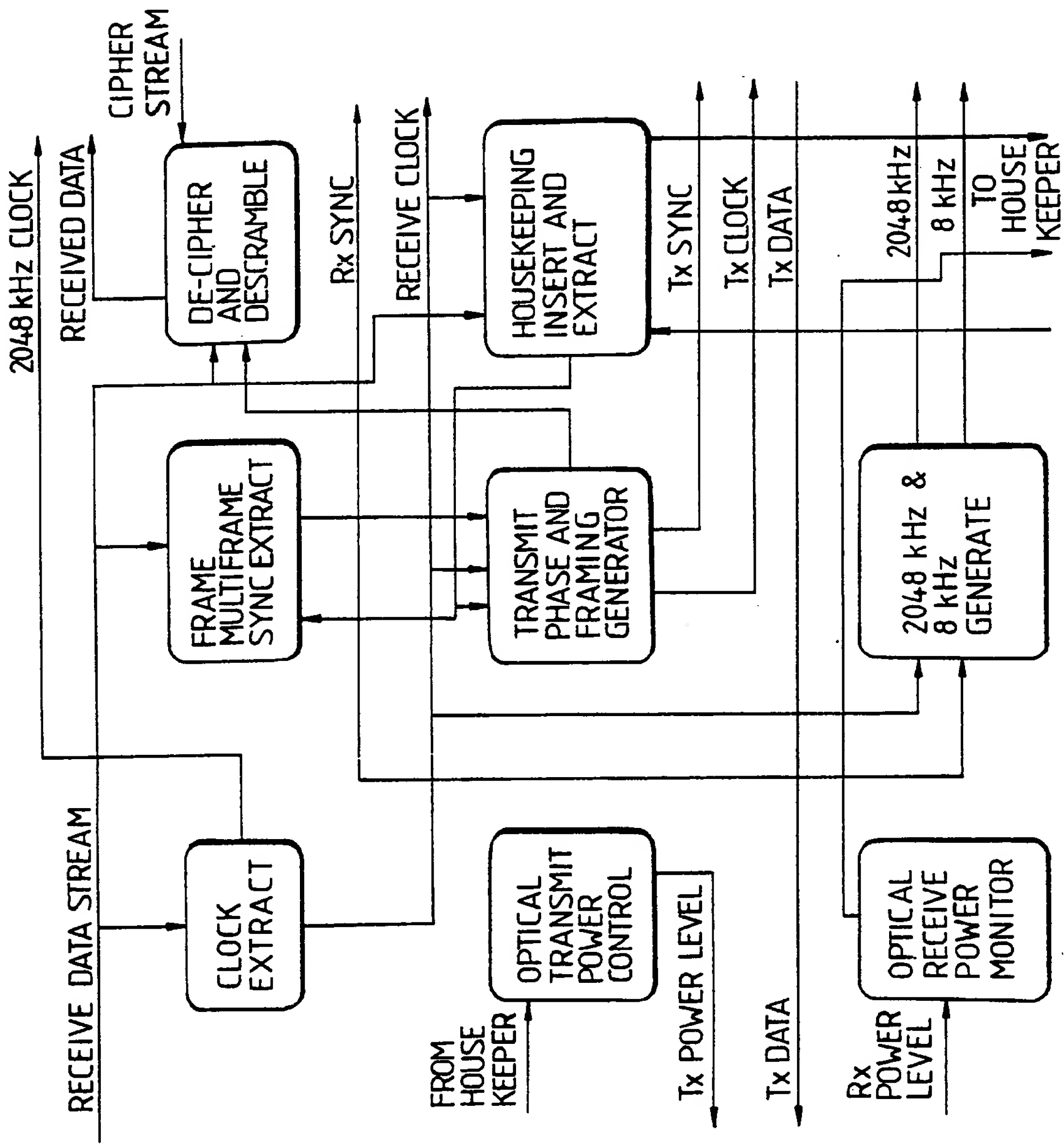
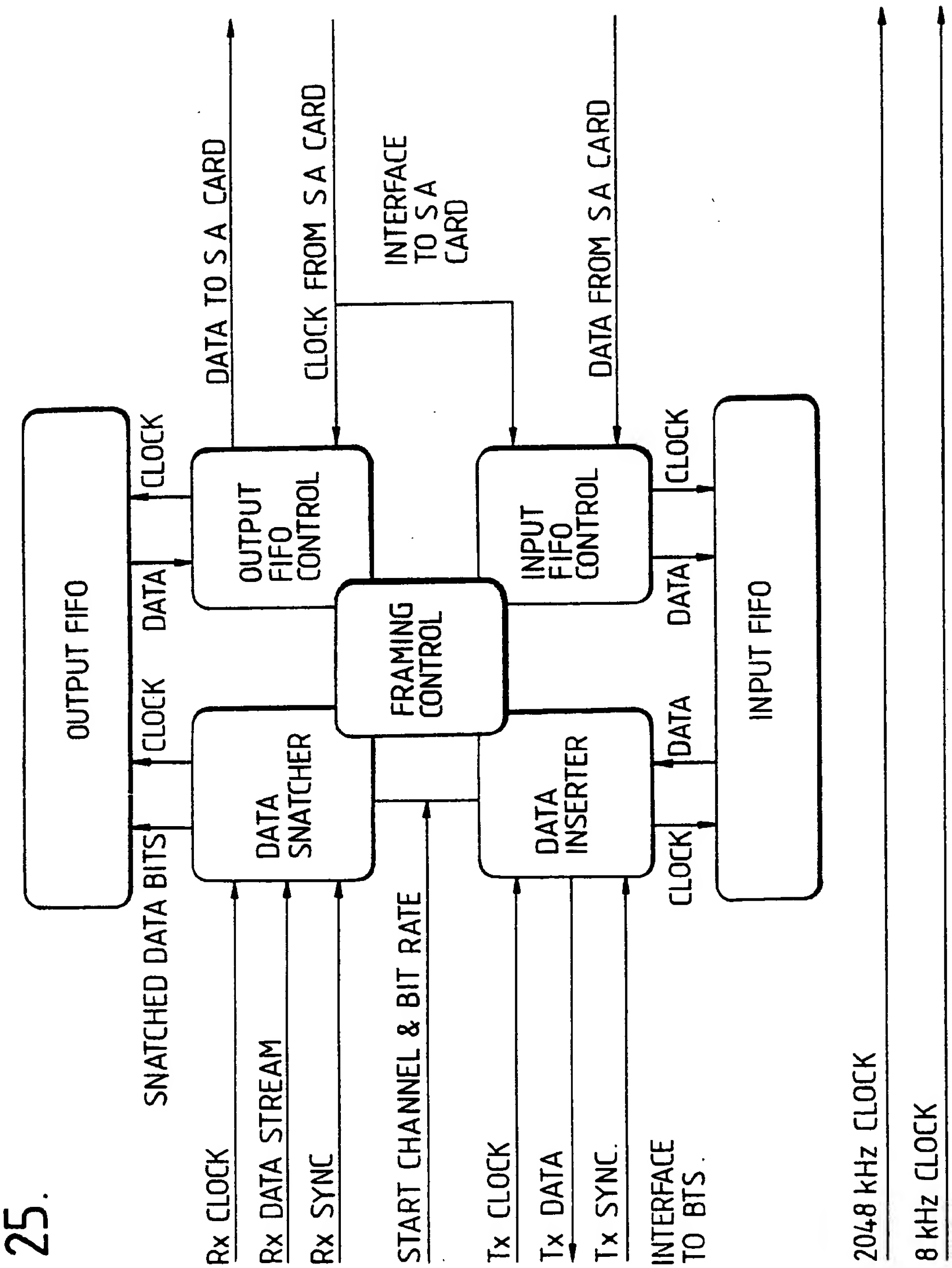

CIPHER STREAM
2048 kHz CLOCK
RECEIVED DATA
DE-CIPHER AND DESCRAMBLE
Rx SYNC
RECEIVE CLOCK
HOUSEKEEPING INSERT AND EXTRACT
Tx SYNC
Tx CLOCK
Tx DATA
2048 kHz
8 kHz
TO HOUSE KEEPER
FRAME MULTIFRAME SYNC EXTRACT
TRANSMIT PHASE AND FRAMING GENERATOR
2048 kHz & 8 kHz GENERATE
RECEIVE DATA STREAM
CLOCK EXTRACT
OPTICAL TRANSMIT POWER CONTROL
FROM HOUSE KEEPER
Tx POWER LEVEL
Tx DATA
OPTICAL RECEIVE POWER MONITOR
Rx POWER LEVEL

Fig. 24.

Fig. 25.


OUTPUT FIFO
CLOCK
DATA
CLOCK
SNATCHED DATA BITS
OUTPUT FIFO CONTROL
DATA SNATCHER
FRAMING CONTROL
INPUT FIFO CONTROL
DATA INSERTER
CLOCK
DATA
DATA
CLOCK
INPUT FIFO
DATA TO S A CARD
CLOCK FROM S A CARD
INTERFACE TO S A CARD
DATA FROM S A CARD
Rx CLOCK
Rx DATA STREAM
Rx SYNC
START CHANNEL & BIT RATE
Tx CLOCK
Tx DATA
Tx SYNC.
INTERFACE TO BTS
2048 kHz CLOCK
8 kHz CLOCK

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 88/00004

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: H 04 B 9/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	H 04 B; H 04 H; H 04 Q

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	GLOBECOM '85, IEEE Global Telecommunications Conference, 2-5 December 1985, New Orleans, Louisiana, volume 3, IEEE, (New York, US), D.B. Payne et al.: "Single mode optical local networks", pages 1001-1005 see page 1202, right-hand column; page 1205, left-hand column; figures 1,2,5	1,3,4,6-9,13-18, 23
A		10,12,20
	--	
X	EP, A, 0138365 (BIRISH TELECOM) 24 April 1985 see page 1, lines 18-22; page 21, lines 6-8; page 22, lines 3-5; claims 5,6,13	1,5
	--	
A	EP, A, 0162994 (HEINRICH-HERTZ) 4 December 1985 see claim 1; page 25, lines 11-19	1
	--	
	./.	

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
14th March 1988	18 APR 1988
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	P.C.G. VAN DER PUTTEN

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	DE, A, 3104404 (GUTEHOFFNUNGSHUTTE) 19 August 1982 see page 5, lines 14-24 --	1,10,20,21
A	EP, A, 0168051 (NEC) 15 January 1986 --	1,5
A	ICC '82, Proceedings of the IEEE International Conference on Communications, 13-17 June 1982, Philadelphia, volume 2, IEEE, (New York, US), P. Gravey: "The wired city of biarritz: a first step to an optical multiservice network", pages 4D.3.1 - 4D.3.5 see figure 2 --	1,10-12, 18,20,21, 23
X	36th Electronic Components Conference, 5-7 May 1986, Seattle, Washington, IEEE, (New york, US), M. Corke: "Fiber optic components", pages 256-265 see figures 20,22	1,21,22

ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO. GB 8800004
SA 20192

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 08/04/88
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A- 0138365	24-04-85	JP-A- 60150345 US-A- 4642806 CA-A- 1227844	08-08-85 10-02-87 06-10-87
EP-A- 0162994	04-12-85	None	
DE-A- 3104404	19-08-82	None	
EP-A- 0168051	15-01-86	JP-A- 61024338 US-A- 4653049 CA-A- 1229436	03-02-86 24-03-87 17-11-87

EPO FORM P0479

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82